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TESTS OF DRY COMPOSITE LUBRICATED GEARS FOR USE IN AN AEROSPACE ENVIRONMENTAL CHAMBER

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FOREWORD

The research reported was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Program Element No. 65402034.

The results of research presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the AEDC, under Contract AF 40(600)-1000. The research was conducted from August 25 to October 23, 1964, under ARO Project No. SM3503, and the report was submitted by the author on February 1, 1965.

Under Research Contract AF 40(600)1071, managed by Technology Division, DCS/Plans and Technology, Arnold Engineering Development Center, the Westinghouse Electric Corporation adapted lubrication techniques, developed under Contract AF 40(600)-915, for satisfying the friction requirements associated with the roll and pitch drive assembly of the Mark I Aerospace Environmental Chamber.

The author wishes to acknowledge the assistance of Mr. Paul Bowen, Westinghouse Project Engineer, who contributed greatly to the planning and execution of the tests described in this report.

This technical report has been reviewed and is approved.

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ABSTRACT

This report contains the results of a test program set up to determine the operational characteristics of dry composite lubricated gears. Two diametral pitch sizes, 7 and 12, and two gear materials, nitralloy steel and nodular iron, were tested. Three dry composite lubricants and one low vapor pressure grease were tested. All three dry composite lubricants provided adequate lubrication for periods of up to 300 hr at 100 rpm with very little wear of either load gears or lubricating idlers. The MoS_2-fortified, grease-lubricated gears failed after 40 hr of operation.

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SECTION I
INTRODUCTION

Experience has shown that conventional fluid lubricants in gears are not satisfactory for extended periods of operation in vacuum chambers at pressures of 10^{-4} torr and lower. This is because of (1) excessive evaporation and sublimation which causes an excessive load on the chamber vacuum pumping system, (2) possible surface contamination of test support equipment as well as test vehicles, and (3) loss of lubricant causing marginal lubrication with possible cold welding of clean surfaces. Development work to date using dry composite lubricating materials has demonstrated that the use of these lubricants is practical and that they can be adapted to various applications in aerospace test chamber support systems. However, before specific dry lubricated gears are produced and installed in a particular testing facility, it is necessary to conduct functional tests of prototypes. These tests determine whether the load life characteristics meet the requirements of satisfactory operation in the particular application.

The vehicle handling system of the Mark I Aerospace Environmental Chamber (Fig. 1) is designed to be capable of supporting and maneuvering a 40,000-lb test vehicle with a 3-g load factor. The operational environment will have a pressure range of from one atmosphere to 1×10^{-8} torr, and a temperature range of from -193 to +100°C. Materials used in this system are corrosion resistant steels with minimum outgassing rates. A minimum gear life of one year of continuous operation is desired without manual relubrication.

The work reported herein concerns the evaluation of self-lubricating composite materials and dry lubrication techniques for two diametral pitch sizes of spur gears which could be used in the Mark I systems.

SECTION II
LUBRICANTS

2.1 THEORY OF DRY LUBRICATION

The theory behind dry film lubrication is simply indicated in Fig. 2. Friction and wear are the results of the welding together of surfaces at their points of contact and the subsequent tearing at the welded junctions when the surfaces slide or roll over one another. The frictional force, F (see Fig. 2), equals the product of the area of real contact, A, and the shear strength of the junction, S. When a hard metal rides over a soft one, the hard body presses or plows into the soft one so that the area of

real contact is large. Even though the shear strength of the junction may be relatively low, the frictional force is large because of the large area of real contact. The frictional force is also large when both bodies are hard since the shear strength of the junctions is large even though the area of real contact is small. The ideal solution to the problem of friction is to deposit and maintain a thin film of material with low shear strength between two hard bodies so that the hard substrate supports the load and keeps the area of real contact at a minimum while the film reduces the shear strength of the junctions. Together, these two factors reduce the frictional force.

2.2 TYPES OF DRY LUBRICATION SYSTEMS

Techniques for the deposition and maintenance of the dry film onto gear tooth surfaces are divided into two types of systems.

2.2.1 Nonreplenishable Systems

Thin dry lubricating films may be applied and bonded directly to gear tooth surfaces by several methods, such as spraying, brushing, vacuum deposition, or electroplating. Usually a fair degree of uniformity is maintained in film thicknesses. These deposited films are expected to lubricate the surfaces on which they are applied for a certain length of duty life. Upon completion of the prescribed duty life, surfaces may or may not be inspected, cleaned, and the film reapplied. However, during the duty life of the particular gear, there is no provision for maintaining the film at its desired thickness. Such a system is said to be nonreplenishable (Ref. 1).

2.2.2 Replenishable Systems

Dry lubricating films may be transferred from a reservoir to the gear tooth surfaces which are to be lubricated. This reservoir can be a quantity of dry lubricating powder packed and sealed into a gear box. An idler gear can provide the lubricant reservoir if it is composed of a dry lubricant such as molybdenum disulfide (MoS_2) or tungsten diselenide (WSe_2) sintered with a powdered metal such as silver or copper, which acts as a matrix. In such systems, the load-carrying gears are meshed with dry composite lubricating idlers which transfer the dry film to the gear teeth and maintain the film at the desired thickness. This report is concerned with such a replenishable lubrication system.

2.3 FUNCTIONS OF THE MAJOR CONSTITUENTS OF THE SOLID COMPOSITE LUBRICANTS TESTED

Several materials were used in each of the idler gears: a powdered metal (copper, silver, or a special alloy); a plastic (PTFE, Teflon®); and a metallic salt (WSe_2, tungsten diselenide). The metal formed a matrix under moderate heat and high sintering pressure, the plastic served as a film forming agent, and the metallic salt carried the normal loads and acted as the lubricating element along with the plastic. The ratio of metal, PTFE, and metallic salt was about 6:3:1 by weight.

2.4 LOW VAPOR PRESSURE GREASE TESTED

On one pair of nodular iron gears, Apiezon® "L", a specially developed low vapor pressure (10^{-10} to 10^{-11} torr at room temperature) petroleum distillate grease with MoS_2 additive, was tested. This test was run so that some comparison between the grease and the solid composite lubricants could be made.

SECTION III
APPARATUS

3.1 FOUR-SQUARE GEAR TESTER

The tester used to support and apply preset loads on the test gears is shown in Figs. 3 and 4. It consisted of two parallel shafts, the drive shaft and the torsion shaft, rigidly supported on a stainless steel base plate. The diameters of the drive shaft and the torsion shaft were 2.00 and 0.45 in., respectively. The torsion shaft was provided with a torque coupler which was used to apply and lock the desired torque into the system; this was done by twisting one face of the torque coupler with respect to the other face by means of loading screws. This design made it possible to measure the torque in the system with strain gages mounted on the torsion shaft. Eight, size 305, ball bearings using dry composite lubricating retainers were used to support the test gears mounted on the two shafts. A bearing was located on each side of the four test gears. The parts of one support bearing assembly are shown in Fig. 5. The two shafts were tied together in the four-square configuration through two pairs of load carrying gears. All four load gears were of the same diameter; however, both pairs were not necessarily of the same diametral pitch. Each load gear was lubricated by a meshing, dry composite lubricating idler mounted above the gear. These lubricating idlers were counterweighted so that the desired film transfer pressure was attained.

3.2 TEST GEARS

3.2.1 Gears

The test gears had a pitch diameter of 4 in. and a pitch angle of 14-1/2 deg. Some of the gears had a diametral pitch of 7 and others 12. All gears had a tooth width of 0.5 in. Two types of gear materials were tested. Some gears were made of Nitralloy steel and nitrided. Other gears were made of nodular iron, flame hardened and nitrided.

The load on each gear tooth was calculated as follows:

$$\text{Load} = \frac{T}{\frac{P.D.}{2}} \cos\theta$$

where

T = Torque on system, in.-lb

P.D. = Pitch diameter of gear, in.

θ = Pitch angle of gears, deg

Thus, for 4-in. P.D. and 14-1/2-deg pitch angle

$$\text{Load} = 0.484T \text{ lb}$$

3.2.2 Idlers

The dry composite lubricating idlers were made with either a diametral pitch of 7 or 12. The 7-D.P. idlers had a pitch diameter of 2.429 in. and the 12-D.P. idlers had a pitch diameter of 2.50 in. All idlers had a tooth width of 0.625 in. The three types of dry composite lubricating materials used in the idlers were (1) copper + PTFE (Teflon) + WSe_2 (tungsten diselenide), (2) silver + PTFE + WSe_2) and (3) special alloy + PTFE + WSe_2. Screening tests showed that optimum film transfer pressure occurred when idlers were counterweighted to give an effective idler load of one pound on the gear being lubricated.

3.3 TEST CHAMBER

The Aerospace Research Chamber (7V), Fig. 6, was used to provide the environment for this test program. The inside of the chamber is 7 ft in diameter and measures 12 ft from door flange to door flange. Both ends are provided with doors which give full 7-ft access to the chamber as shown in Fig. 7. The pumping system for this test program consisted of one end cryopanel cooled to 77°K for pumping water vapor, and two

32-in. diffusion pumps, each in series with one of two 6-in. diffusion pumps and backed by a single mechanical pump. Liquid-nitrogen-cooled baffles were employed with the 32-in. diffusion pumps to retard diffusion pump oil backstreaming into the chamber.

3.4 INSTRUMENTATION

Strain gages were used to measure the system torque in the Four-Square Gear Tester during tester loading and calibration. System torque was not measured during testing operations. However, the driving torque was measured throughout the duration of the test by means of a slip ring/strain gage shaft coupling as shown in Fig. 8. This torque was recorded hourly. Copper-constantan thermocouples were used as sensors for representative temperatures on the tester. It was necessary to transmit three of these thermocouple voltage signals through another slip ring assembly since three temperatures being monitored were on rotating hardware. One was located on the side of a gear tooth, another near the hub of the same gear, and the third at the inner race of one of the support bearings. Figure 3 shows the thermocouple slip ring assembly. All temperatures of both stationary and rotating hardware were recorded each hour during the test. Solenoids were used to retract brushes from both slip ring assemblies when readings were not being made. Chamber pressure was measured with two nude ionization gages.

3.5 DRIVE SYSTEM AND ROTARY FEEDTHROUGH SEAL

The Four-Square Gear Tester was driven by a 1-hp, variable speed, a-c motor (see Fig. 7). Input speed to the gear tester was 100 rpm. Since it was necessary that the drive mechanism be located outside the vacuum chamber, a vacuum-tight rotary feedthrough seal was employed. This seal used two guard vacuum cavities around the drive shaft, as shown in Fig. 9. The cavity nearest the drive motor was maintained at a pressure between 1 and 10 microns by use of a mechanical pump. The cavity nearest the tester was maintained at a pressure less than 1 micron by use of a 2-in. diffusion pump backed by a mechanical pump. The performance of this rotary seal was excellent. Chamber pressures as low as 1.2×10^{-8} torr were attained and maintained during these tests with the rotary seal operating at speeds of 100 rpm for 100 hr.

SECTION IV
PROCEDURE

4.1 TESTER ASSEMBLY

Test gears and idlers were marked for identification, cleaned, and weighed before assembly on the tester. The weighing was done on an analytical balance to an accuracy of ±0.01 gm. Each item was photographed and weighed again after testing. The support bearings and test gears were pressed onto the drive shaft and torsion shaft in the configuration shown in Fig. 3. Spacers were used between bearing races and gear hubs to exactly align meshing gears. After assembly, thermocouples were attached to the side of one gear tooth, the hub of the same gear, and the inner race of one support bearing.

4.2 CALIBRATION OF STRAIN GAGES

Strain gages on the torsion shaft were calibrated by applying known torque loads up to 1100 in. -lb to the torsion shaft and recording the needle deflection on a strain-gage indicator. The drive torque strain gages were calibrated by applying known torque loads up to 100 in. -lb to the drive shaft and recording the needle deflection on a strip chart recorder.

4.3 PRELOADING GEARS

After tester assembly was completed, the zero position of the strain-gage indicator was checked with no torque in the system. The gears were coated with a slurry of MoS_2 and alcohol, a small torque load was applied to the system through the torque coupling (see Fig. 3), and then the system was run for approximately 30 minutes in air. After the run-in period, the gears were again coated with MoS_2. Next, the full test preload was applied through the loading screws on the torque coupling. The strain-gage leads were then disconnected from the indicator and wrapped around the torsion shaft and taped to prevent interference during rotation. System load torque was not monitored during the test.

SECTION V
RESULTS

Table I shows gear test conditions and tabulated results. The following information covers detailed results obtained.

5.1 TEST 1

In this test, two 7-D. P. steel gears were tested using one Cu + PTFE + WSe_2 lubricating idler gear running in position 1 (see Fig. 3). Two 7-D. P. nodular iron gears were also tested using Apiezon "L" grease fortified with MoS_2 as a lubricant. These gears were preloaded to 600 in. -lb torque, which gave a tangential tooth load of 290 lb. This test configuration ran for 40 hr and at this point was suspended because of high torque. Figure 10 shows drive torque, gear tooth temperature, and chamber ambient temperature as functions of test time. It was found that the grease-lubricated 7-D. P. nodular iron gears had worn considerably (see Fig. 11). They were replaced with two 12-D. P. nodular iron gears with one Ag alloy + PTFE + WSe_2 lubricating idler gear running in position I-3 (see Fig. 3). The two steel gears and Cu + PTFE + WSe_2 idler were left in place and the test was resumed, but this time at an increased preload torque of 100 in. -lb which gave a tangential tooth load of 532 lb. The remaining 60 hr of the scheduled 100-hr test were completed with this configuration. Figure 12 shows the two 12-D. P. nodular iron gears and the Ag alloy + PTFE + WSe_2 lubricating idler after 60 hr of testing. Figure 13 shows the two 7-D. P. steel gears and the Cu + PTFE + WSe_2 lubricating idler after a total of 100 hr testing.

5.2 TEST 2

In this test, two 7-D. P. nodular iron gears were tested using two Cu + PTFE + WSe_2 lubricating idler gears running in positions 1 and 2 (see Fig. 3). Two 12-D. P. nodular iron gears were also tested using two Cu + PTFE + WSe_2 lubricating idler gears running in positions 3 and 4. These gears were preloaded to 1100 in. -lb torque which gave a tangential tooth load of 532 lb. Figure 14 shows drive torque, gear tooth temperature, and chamber ambient temperature as functions of test time. This test configuration ran for 17 hr at which point one of the gear teeth on the 12-D. P. nodular iron gear in position G-3 sheared and jammed the tester (see Figs. 15 and 16). The two 12-D. P. nodular iron gears were replaced with two more 12-D. P. nodular iron gears using the same two Cu + PTFE + WSe_2 lubricating idler gears as were used in the previous 17 hr of testing, and the test was resumed. The remaining 83 hr of the scheduled 100-hr test were completed with this configuration. Figure 17 shows the first two 12-D. P. nodular iron replacement gears after 83 hr of testing. Figure 18 shows the two 7-D. P. nodular iron gears after 100 hr of testing. Figure 19 shows the lubricating idlers after 100 hr of testing.

5.3 TEST 3

In this test, two 7-D. P. steel gears were tested using two Ag alloy + PTFE + WSe_2 lubricating idler gears running in positions 1 and 2 (see Fig. 3). Two 12-D. P. steel gears were also tested using two Cu + PTFE + WSe_2 lubricating idlers running in positions 3 and 4. These gears were also preloaded to 100 in.-lb torque (532-lb tangential tooth load). This test configuration ran for 52 hr at which point testing was suspended because the idler in position 4 moved axially out of alignment with the gear in position 4. The chamber was opened, idler I-4 was removed, and testing was resumed using only idler I-3 to lubricate the G-3/G-4 gear assembly. The remaining 48 hr of the scheduled 100-hr test were completed with this configuration. Figure 20 shows drive torque, gear tooth temperature, and chamber ambient temperature as functions of test time. Figure 21 shows the two 7-D. P. steel gears after 100 hr of testing. Figure 22 shows the two 12-D. P. steel gears after 100 hr of testing. Note the appearance of gear No. N124 N, which was the G-4 position gear. The difference in shading of one side from the other is the result of the idler (I-4) partially moving axially out of alignment with this gear. This difference in shading is caused by the lubricating film being thicker on the side which remained in contact with the idler after it partially moved out of alignment with the gear. Figure 23 shows the lubricating idlers (Ag 71, Ag 72, and Cu 123 after 100 hr of testing, and Cu 124 after 52 hr of testing). Note the slight difference in wear of one side from the other on Cu 124.

5.4 TEST 4

In this test, two 7-D. P. steel gears were tested using two Ag alloy + PTFE + WSe_2 lubricating idler gears running in positions 1 and 2 (see Fig. 3). Two 7-D. P. nodular iron gears were also tested using two Ag alloy + PTFE + WSe_2 lubricating idler gears running in positions 3 and 4. Preload was again 1100 in.-lb torque (532-lb tangential tooth load). This test configuration ran the scheduled 100 hr without difficulty. Figure 24 shows drive torque, gear tooth temperature, and chamber ambient temperature as functions of test time. Figure 25 shows the two 7-D. P. steel gears after 100 hr of testing. Figure 26 shows the two 7-D. P. nodular iron gears after 100 hr of testing. Figure 27 shows the lubricating idlers after 100 hr of testing.

5.5 TESTS 5A AND B

In these tests, two 7-D. P. nodular iron gears were tested using two Cu + PTFE + WSe_2 lubricating idler gears running in positions 1 and 2 (see Fig. 3). Two 12-D. P. nodular iron gears were also tested using

two special alloy + WSe_2 lubricating idler gears running in positions 3 and 4. These gears were preloaded to 1100 in.-lb (532-lb tangential tooth load). This test configuration ran a scheduled 100 hr (Test 5A), at which point the gears and idlers were removed from the tester, photographed, weighed, and then reinstalled in the tester.

Testing was then resumed (Test 5B) with gears and idlers in the same position and under the same loading conditions as before. An additional 200 hr of testing was recorded on these gears without difficulty at which point all scheduled testing was complete. Figure 28 gives drive torque, gear tooth temperature, and chamber ambient temperature as functions of test time. Figure 29 shows a 7-D. P. nodular iron gear (position G-2) and lubricating idler (position I-2) after the first 100 hr of testing. Figure 30 shows a 12-D. P. nodular iron gear (position G-4) and lubricating idler (position I-4) after the first 100 hr of testing. Figure 31 shows the two 7-D. P. nodular iron gears after 200 hr of testing (Test 5B). Figure 32 shows the two 12-D. P. nodular iron gears after 200 hr of testing (Test 5B). Figure 33 shows the lubricating idlers used in Tests 5A and B. The high degree of wear on idler No. 76 is clearly shown. This idler ran in position I-2. During test 5B, the counterbalancing weight worked itself out beyond the equilibrium point, causing the idler to ride up and out of mesh with gear G-2. The counterbalancing weight would then vibrate back to the other side of the equilibrium point and the idler would move back down into mesh with gear G-2. This up and down action resulted in an accelerated wear of the idler gear; however, lubrication of the gear was still adequate.

SECTION VI
SUMMARY OF RESULTS

Gears in this test were heavily loaded with Hertz stresses up to 199,000 psi (compared with Hertz stresses of 67,700 psi on thin film lubricated gears previously tested, Ref. 6). Gears in this test were operated for as much as 300 hr at 100 rpm, compared with 250 hr at 11 rpm in the case of the thin film lubricated gears previously tested.

Both gear materials tested gave good results as did both diametral pitch sizes. All three dry composite lubricants tested gave good results. From the standpoint of lubricant wear (see Table II), the 12-D. P. Cu + PTFE + WSe_2 and the 12-D. P. Ag alloy + PTFE + WSe_2 idlers were the best. They provided good lubrication with the lowest percentage of reservoir depletion (wear) of any of the composites tested.

The MoS_2-fortified Apiezon "L" grease was not a successful lubricant for the gears on which it was tested. Considerable wear on the gears was experienced.

SECTION VII
CONCLUDING REMARKS

Dry composite lubrication will have many varied applications in space environmental chambers. The ability of these composite materials to lubricate various gear materials in various geometric configurations with the gears under heavy loads and at moderate speeds (100 to 300 rpm) has been shown. Furthermore, the capability of replenishment of the lubricating film will be of great significance when considering extended duration testing and use of inaccessible mechanisms.

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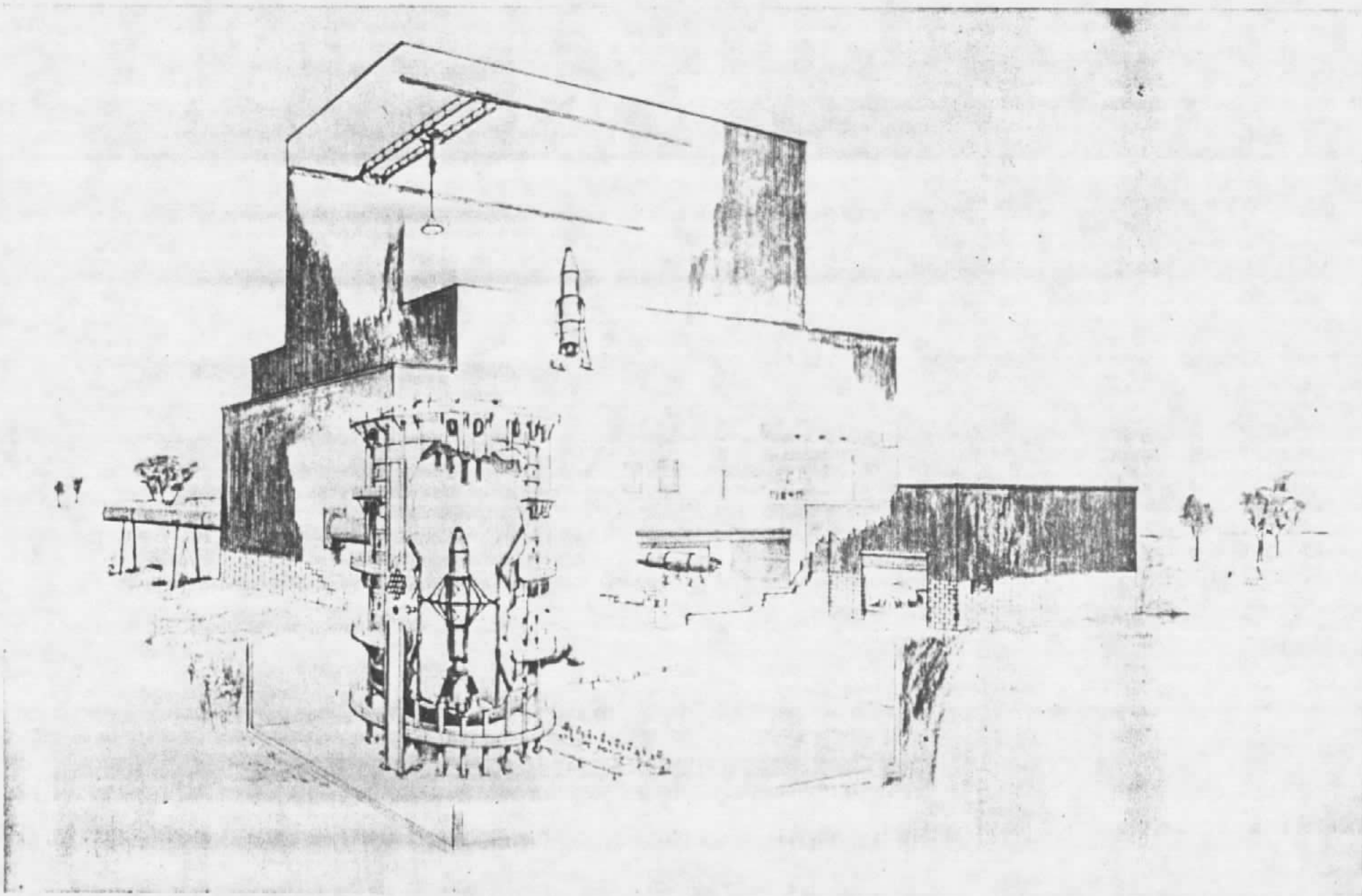

Fig. 1 Mark I Aerospace Environmental Chamber

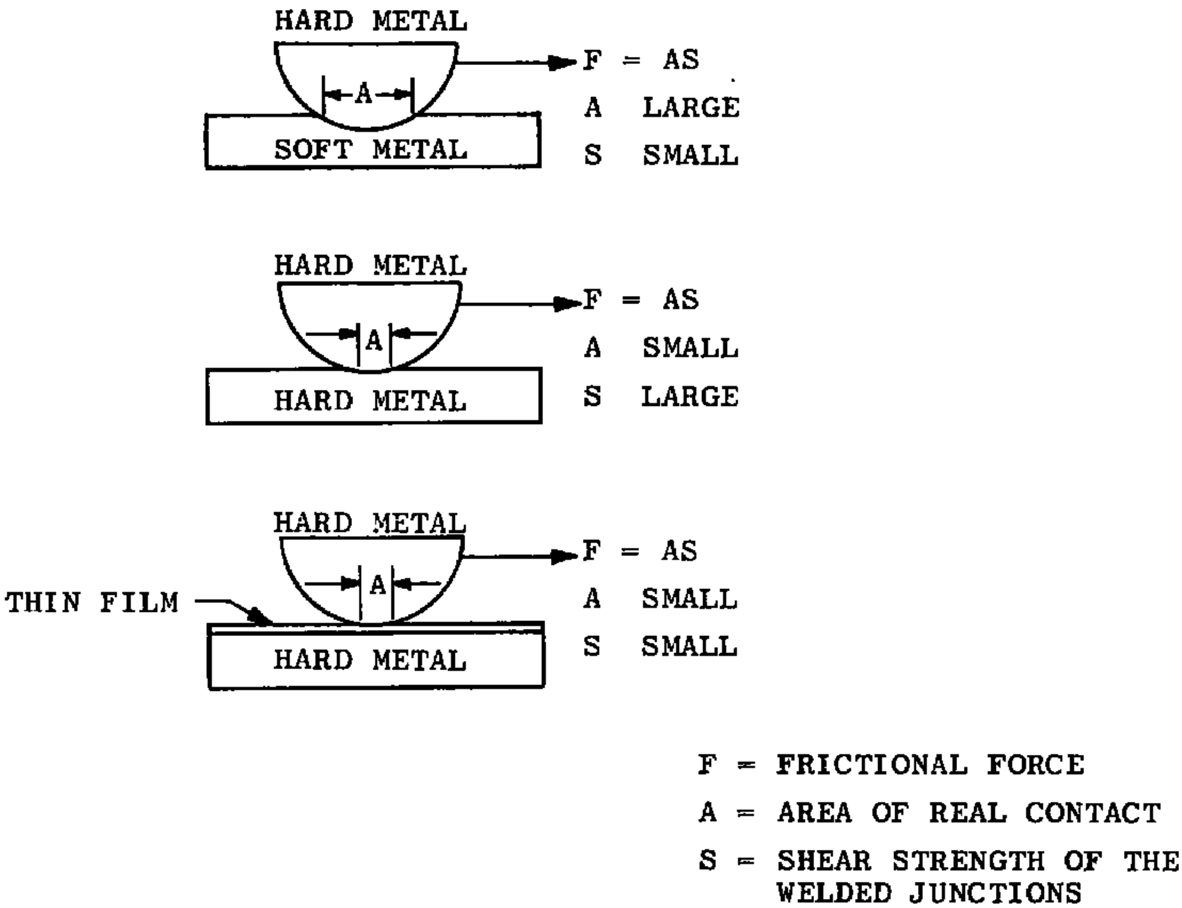

Fig. 2 Theory of Dry Film Lubrication

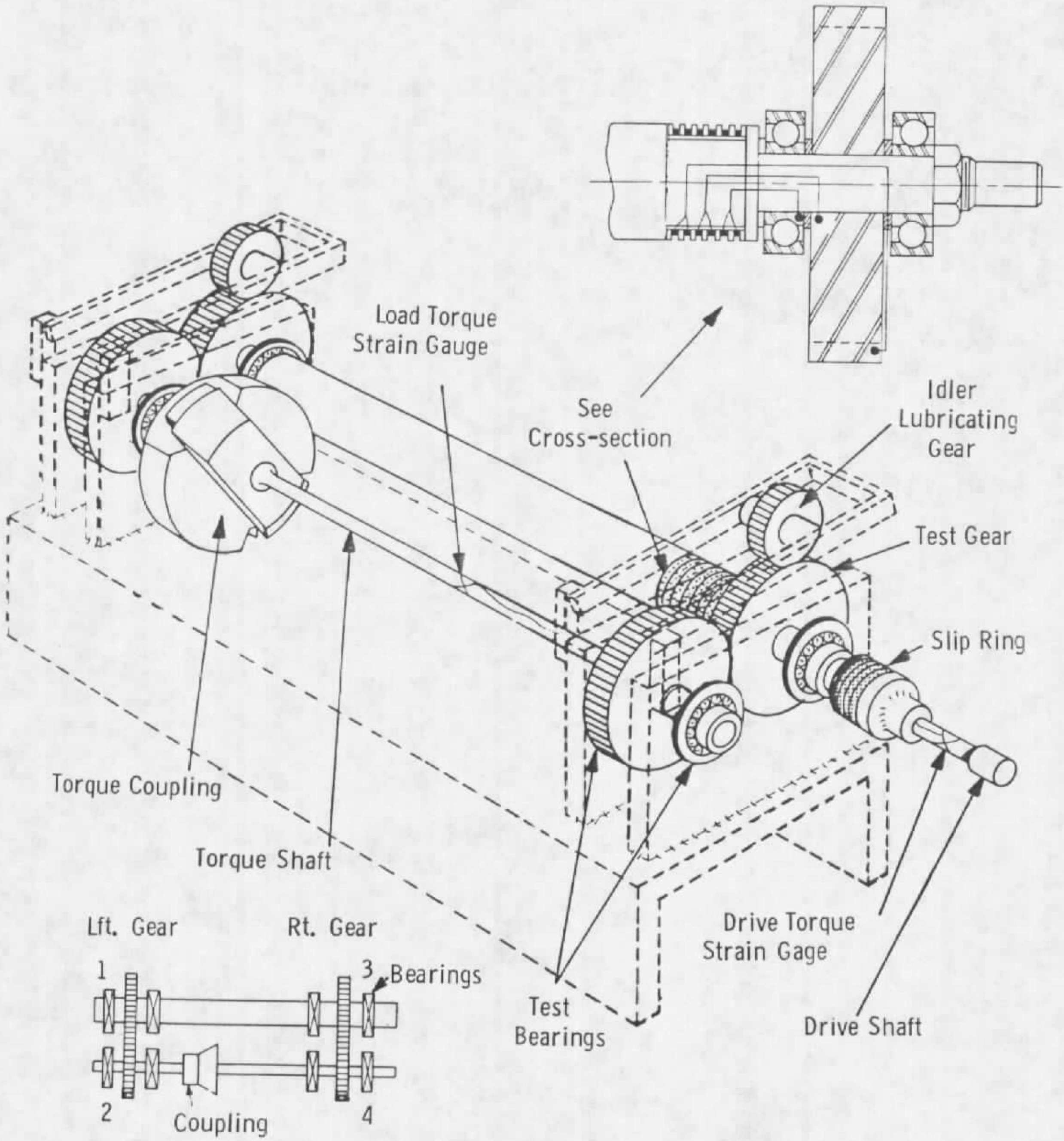

Fig. 3 Gear Tester (Artist's Conception)

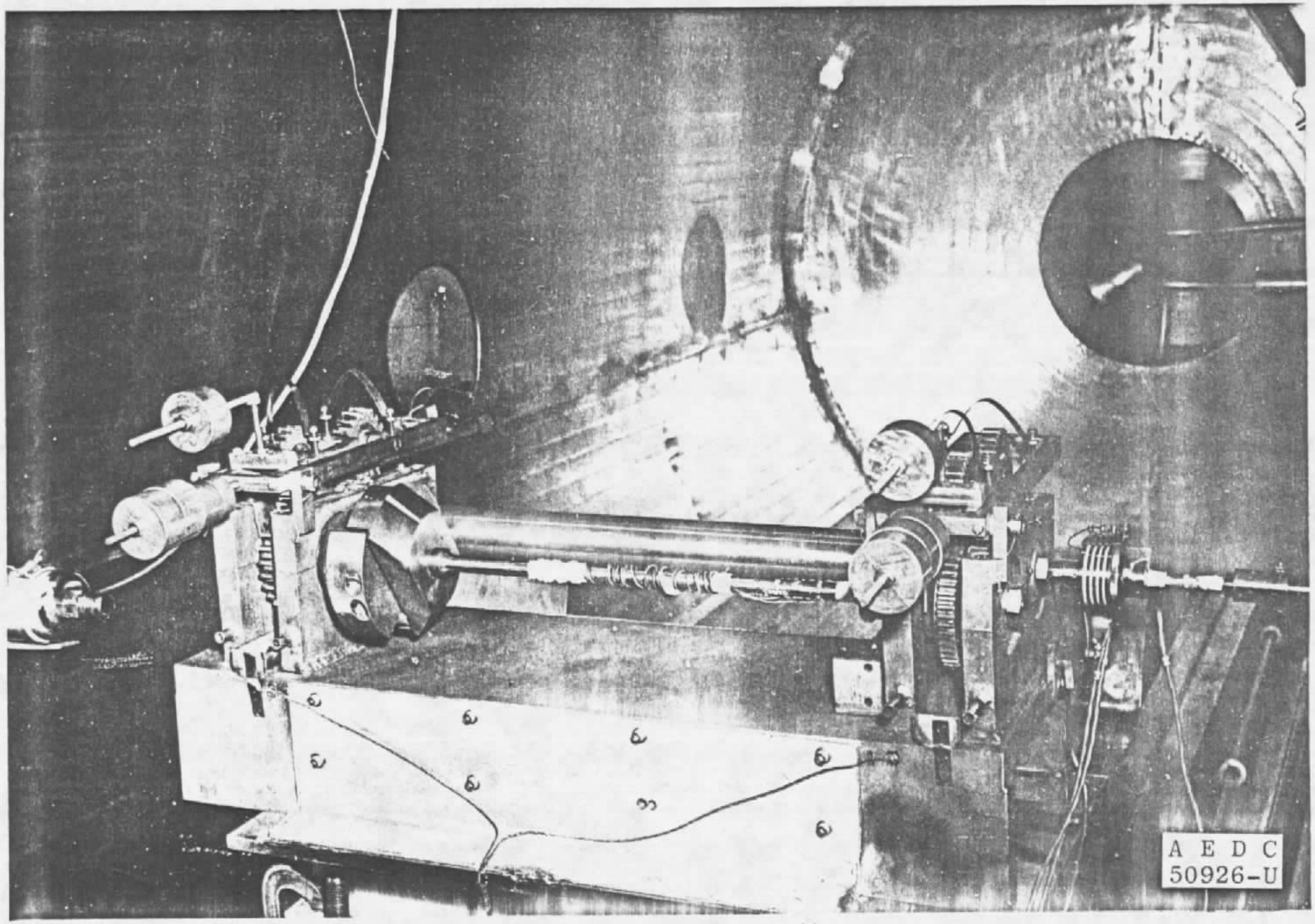

Fig. 4 Gear Tester (Photograph)

Photograph Supplied by Westinghouse Electric Corp.

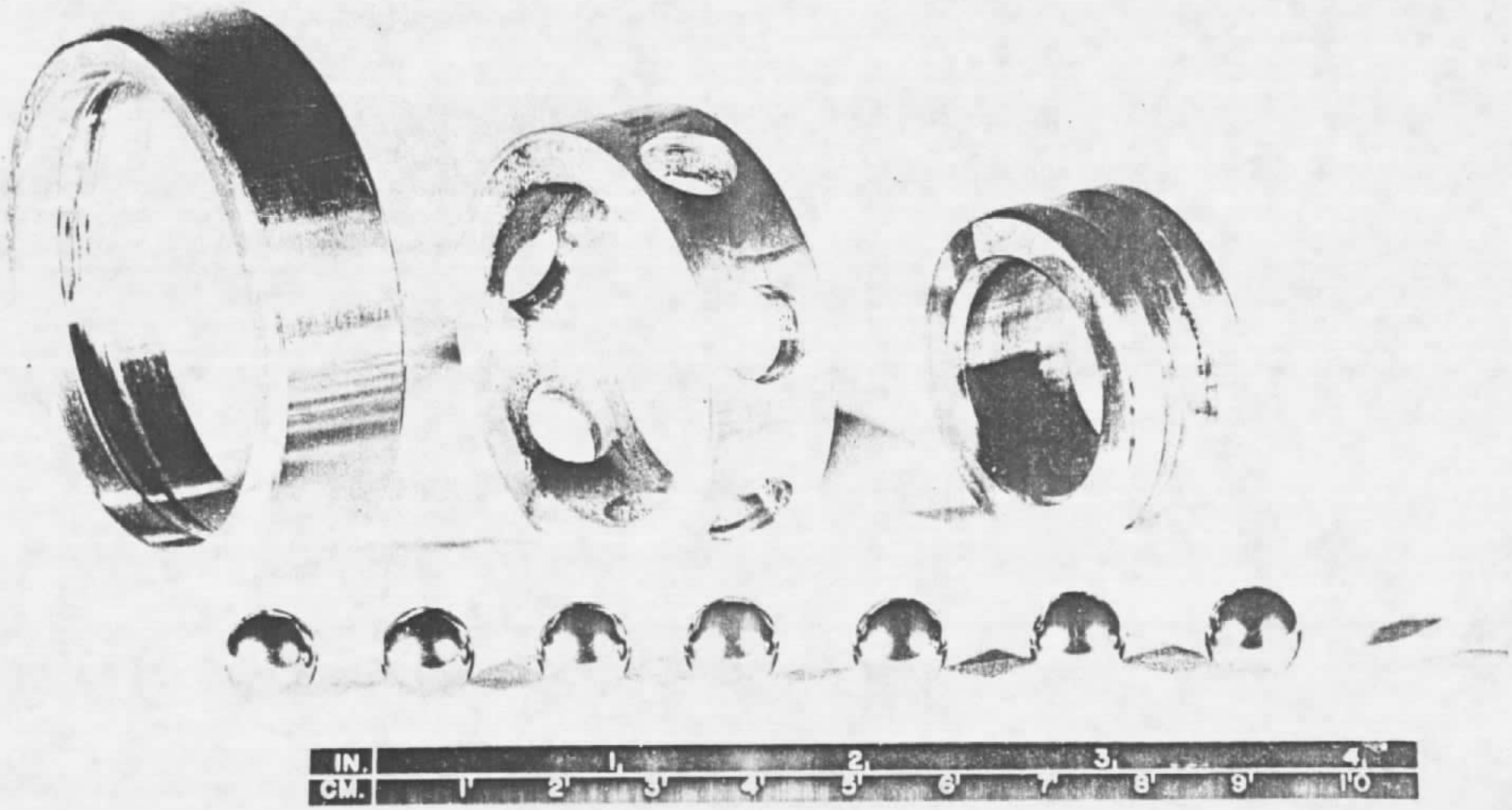

Fig. 5 Solid Composite Lubricated Support Bearing

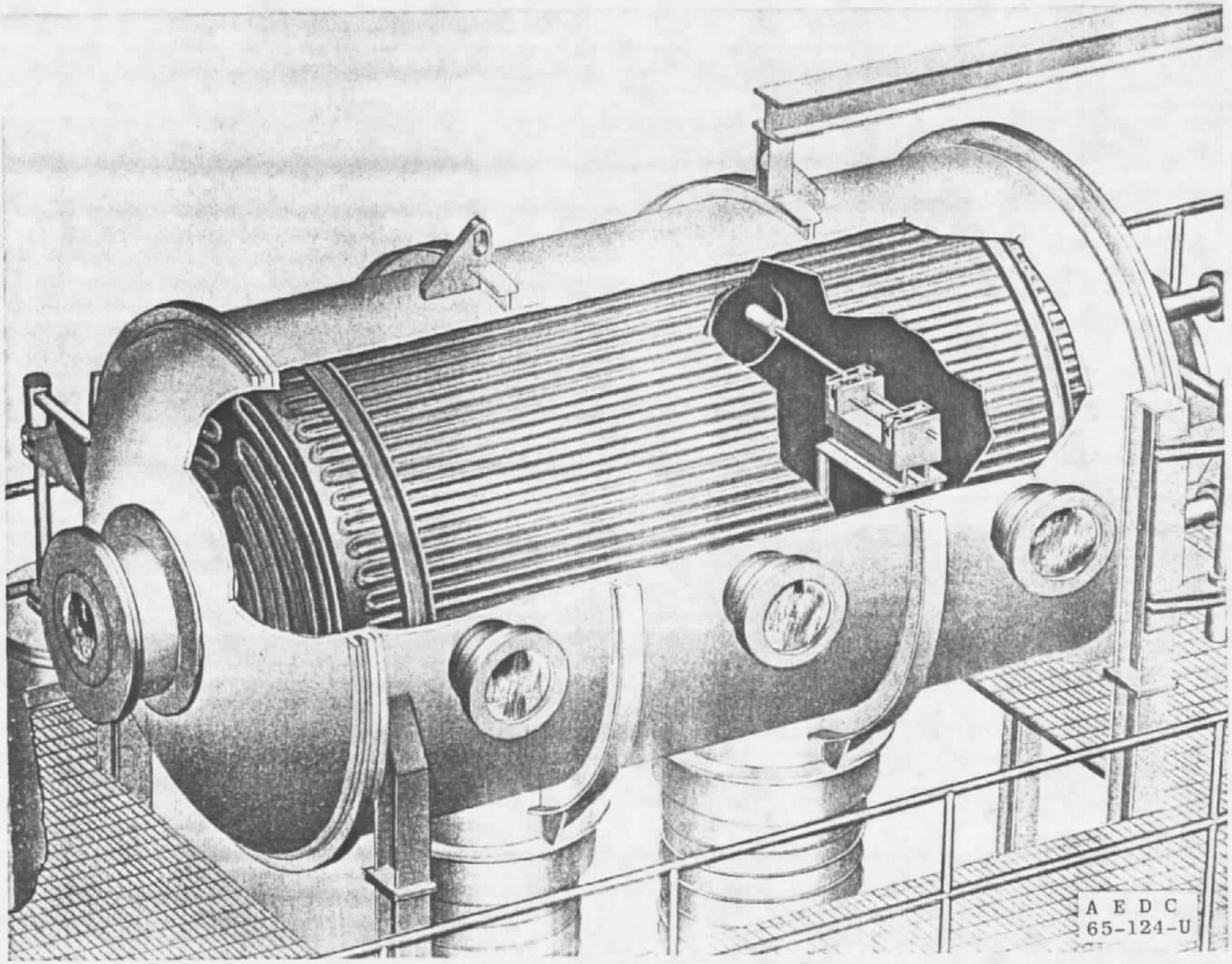

Fig. 6 Aerospace Research Chamber (7V)

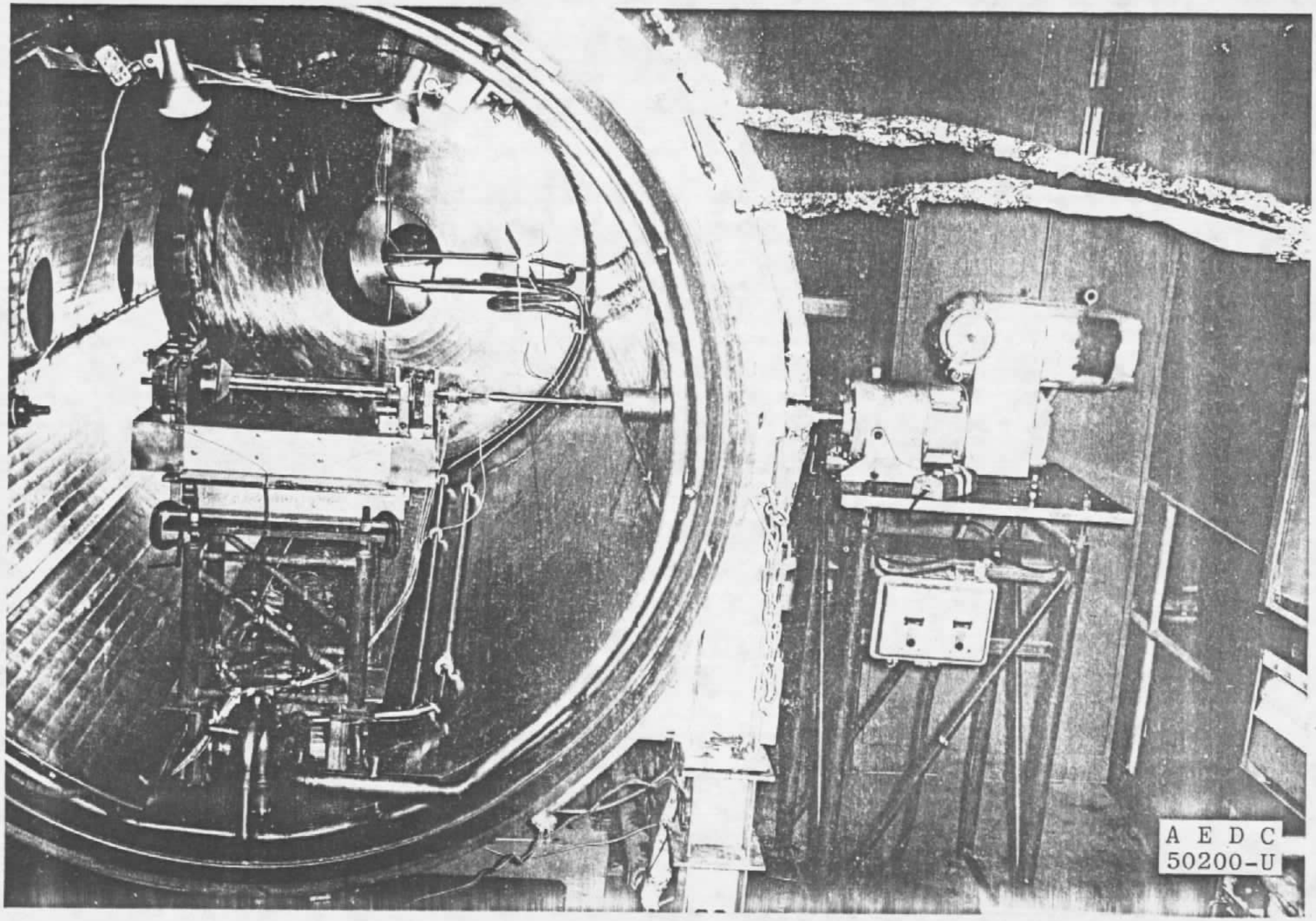

Fig. 7 Gear Tester Assembly Installed in ARC (7V)

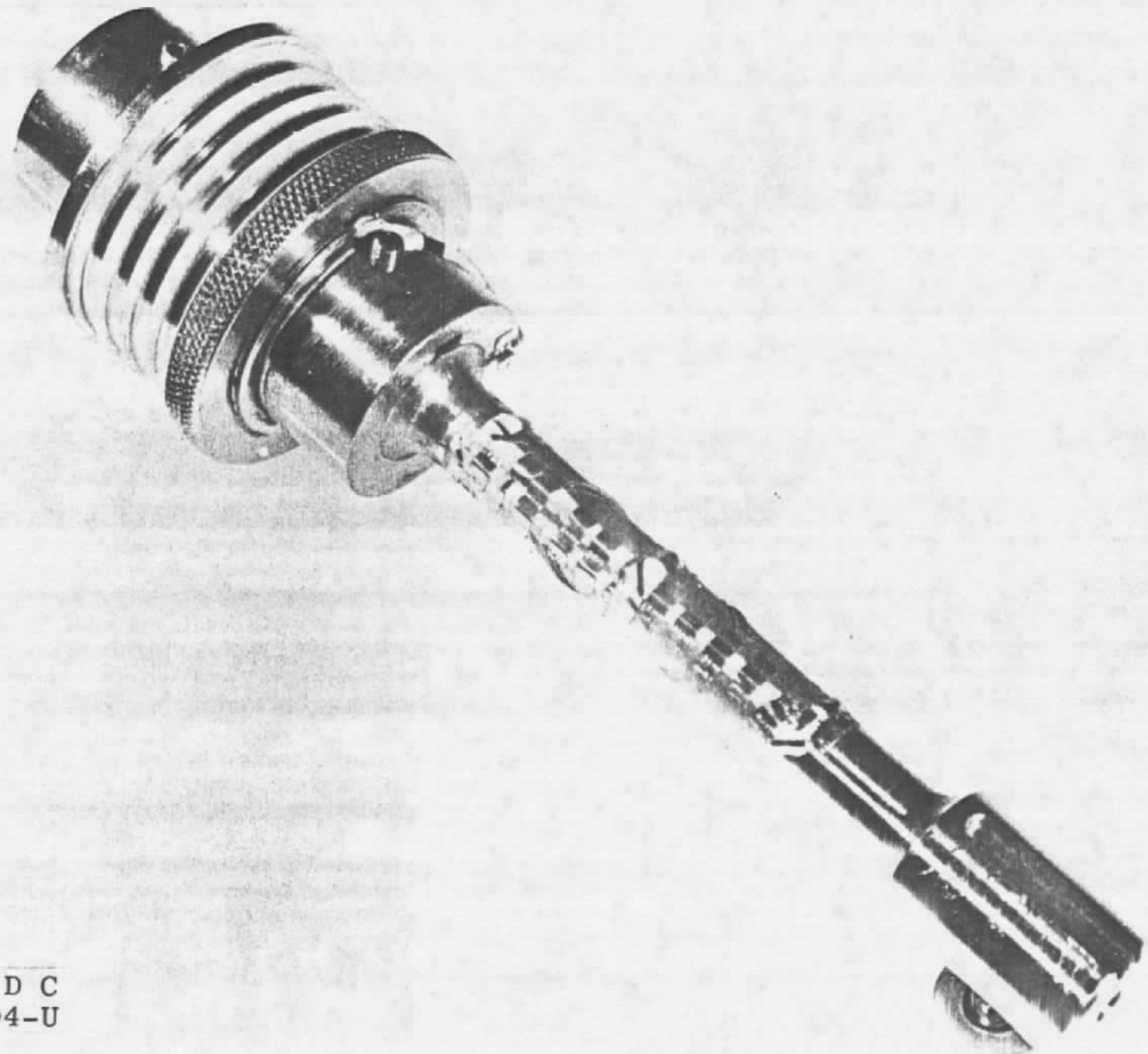

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Fig. 8 Slip Ring/Strain Gage Shaft Coupling

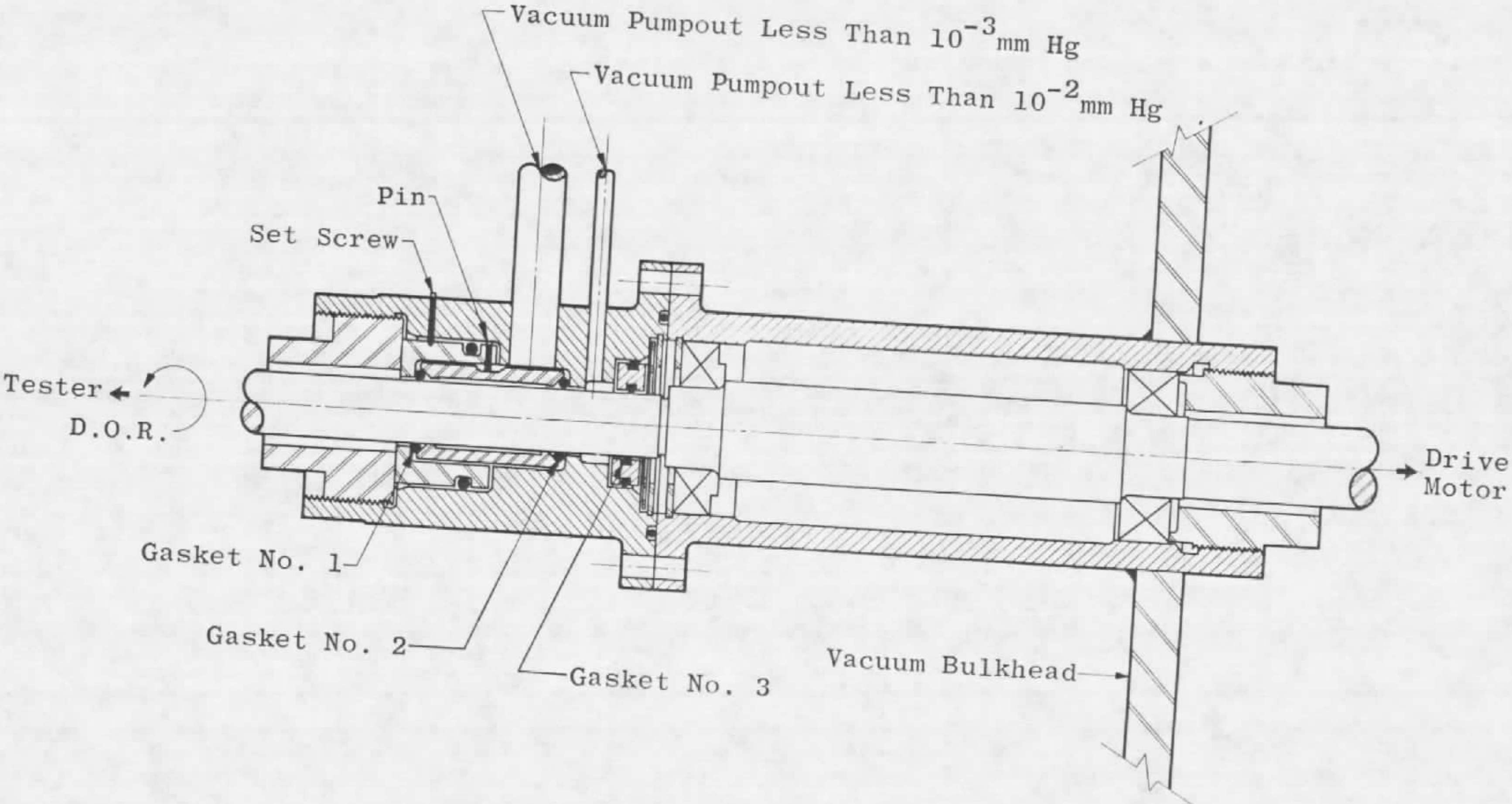


Fig. 9 Rotary Feedthrough Seal

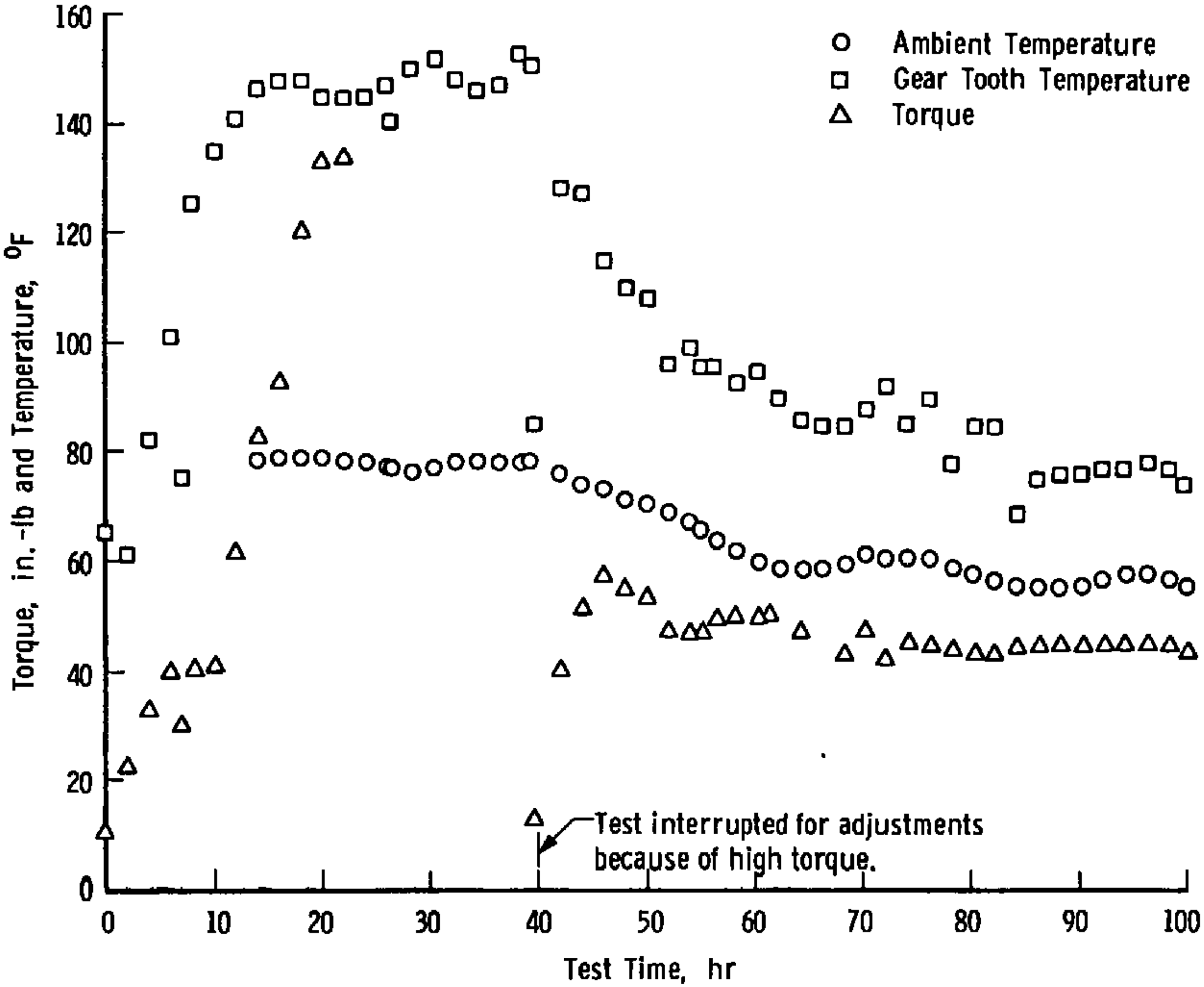
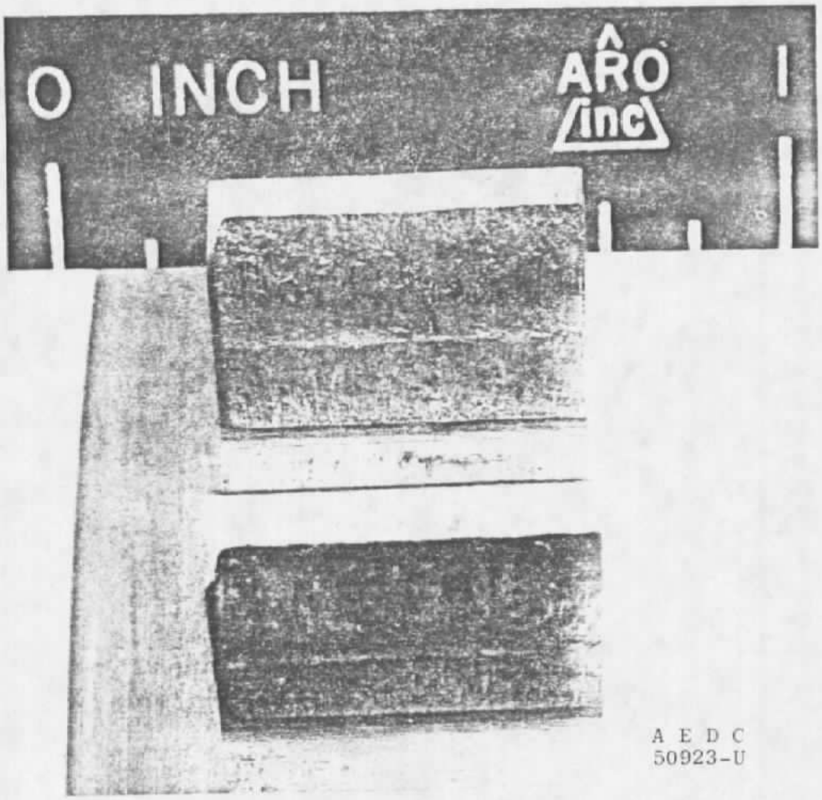


Fig. 10 Drive Torque, Gear Tooth Temperature, and Chamber Ambient Temperature versus Test Time for Test 1



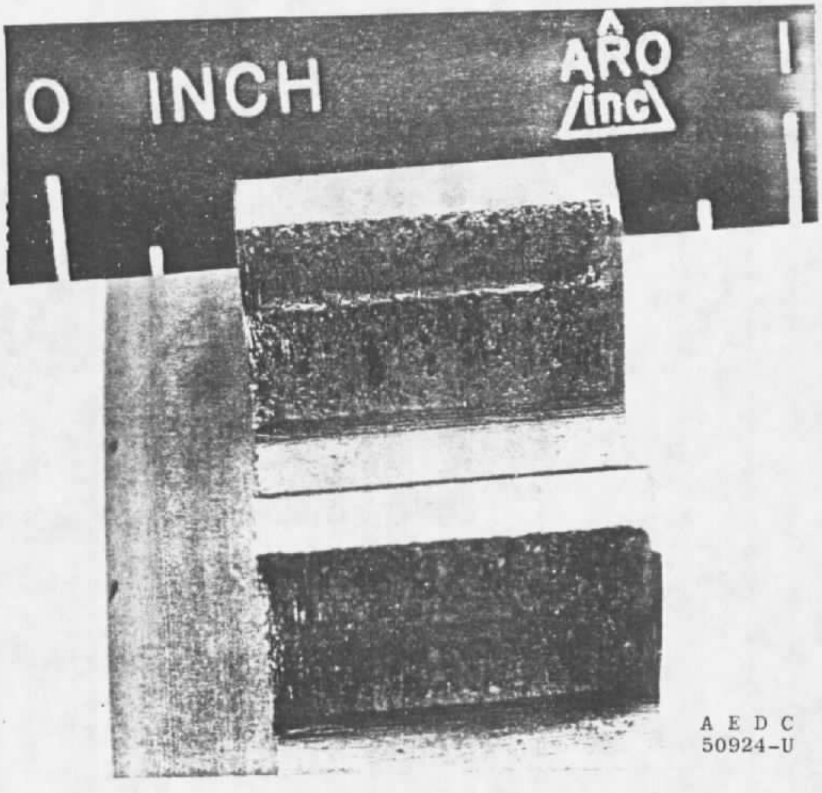


Fig. 11 7-D.P. Nodular Iron Grease Lubricated Gears after 40 hr in Test 1

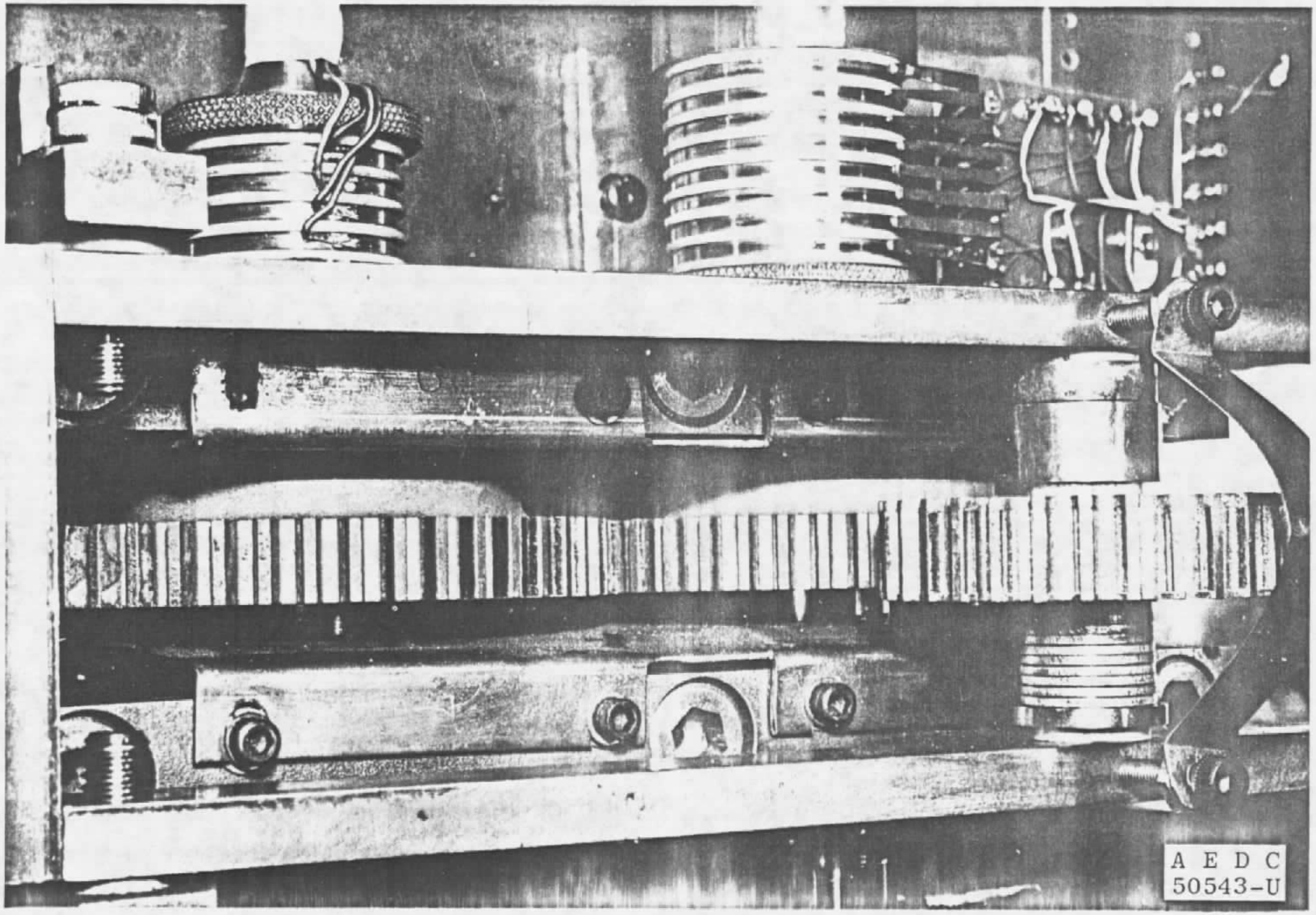


Fig. 12 12-D.P. Nodular Iron Gears and Ag Alloy + PTFE + WSe_2 Lubricating Idler after 60 hr in Test 1

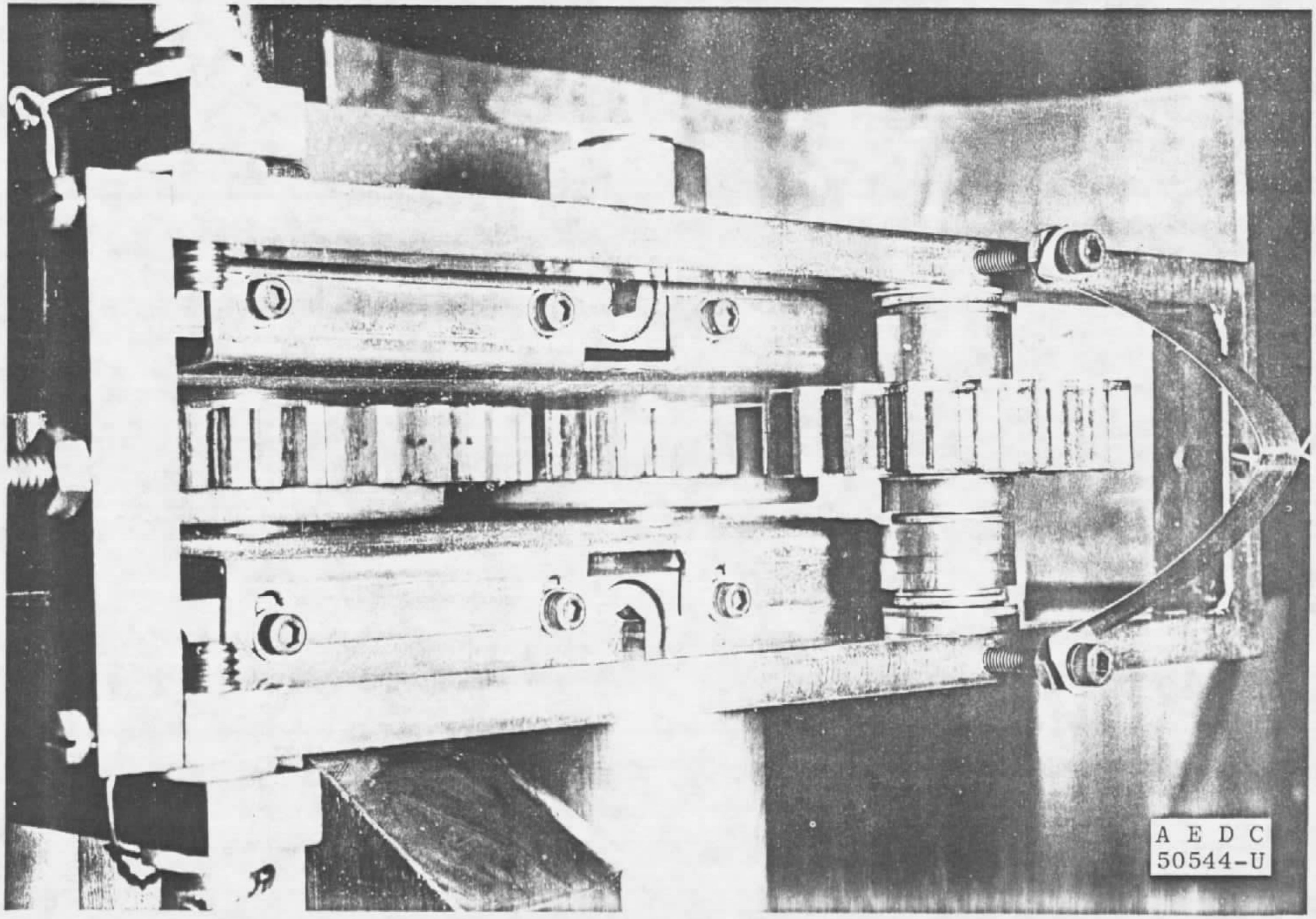


Fig. 13 7-D.P. Steel Gears and Cu + PTFE + WSe_2 Lubricating Idler after 100 hr in Test 1

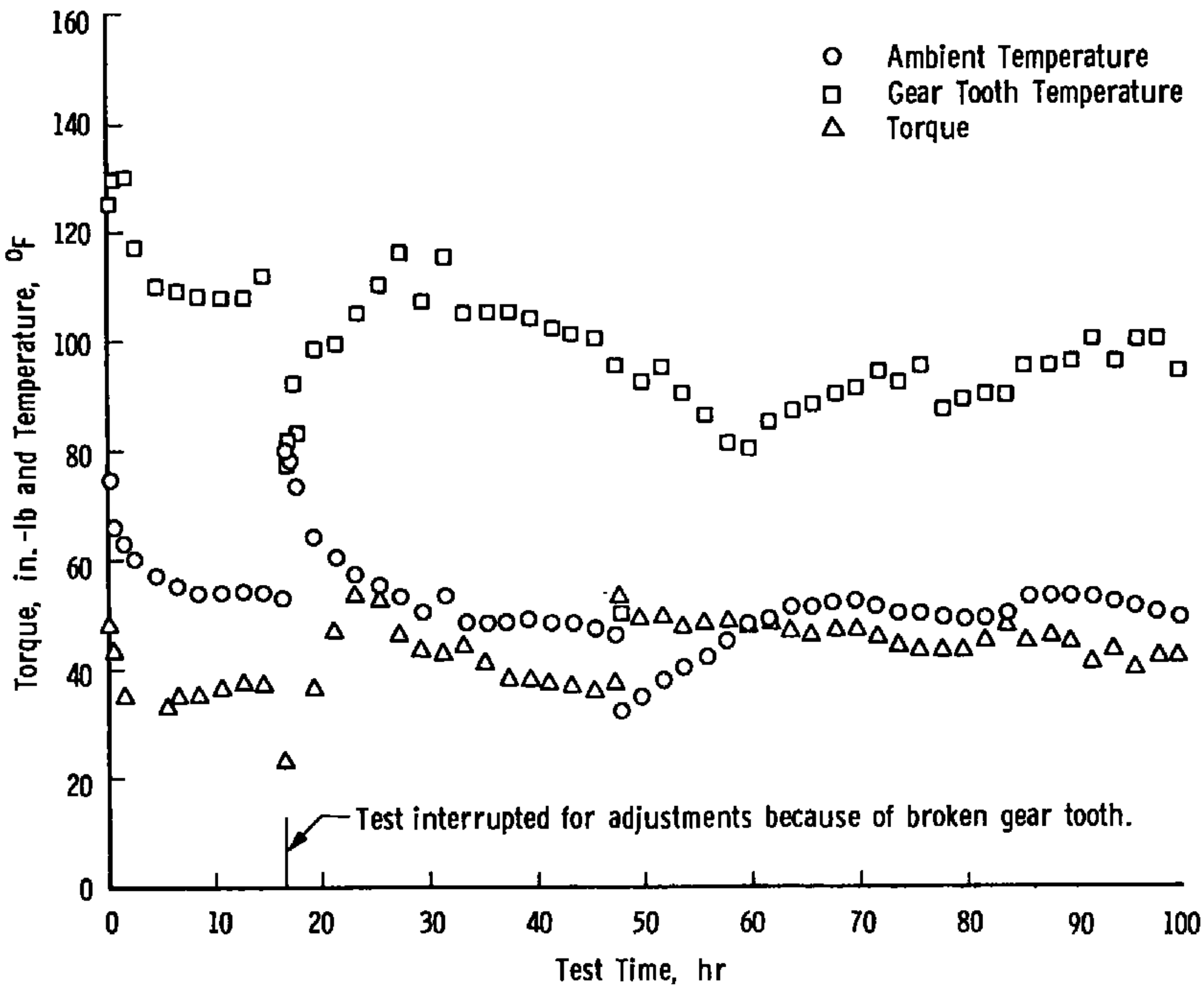


Fig. 14 Drive Torque, Gear Tooth Temperature, and Chamber Ambient Temperature versus Test Time for Test 2

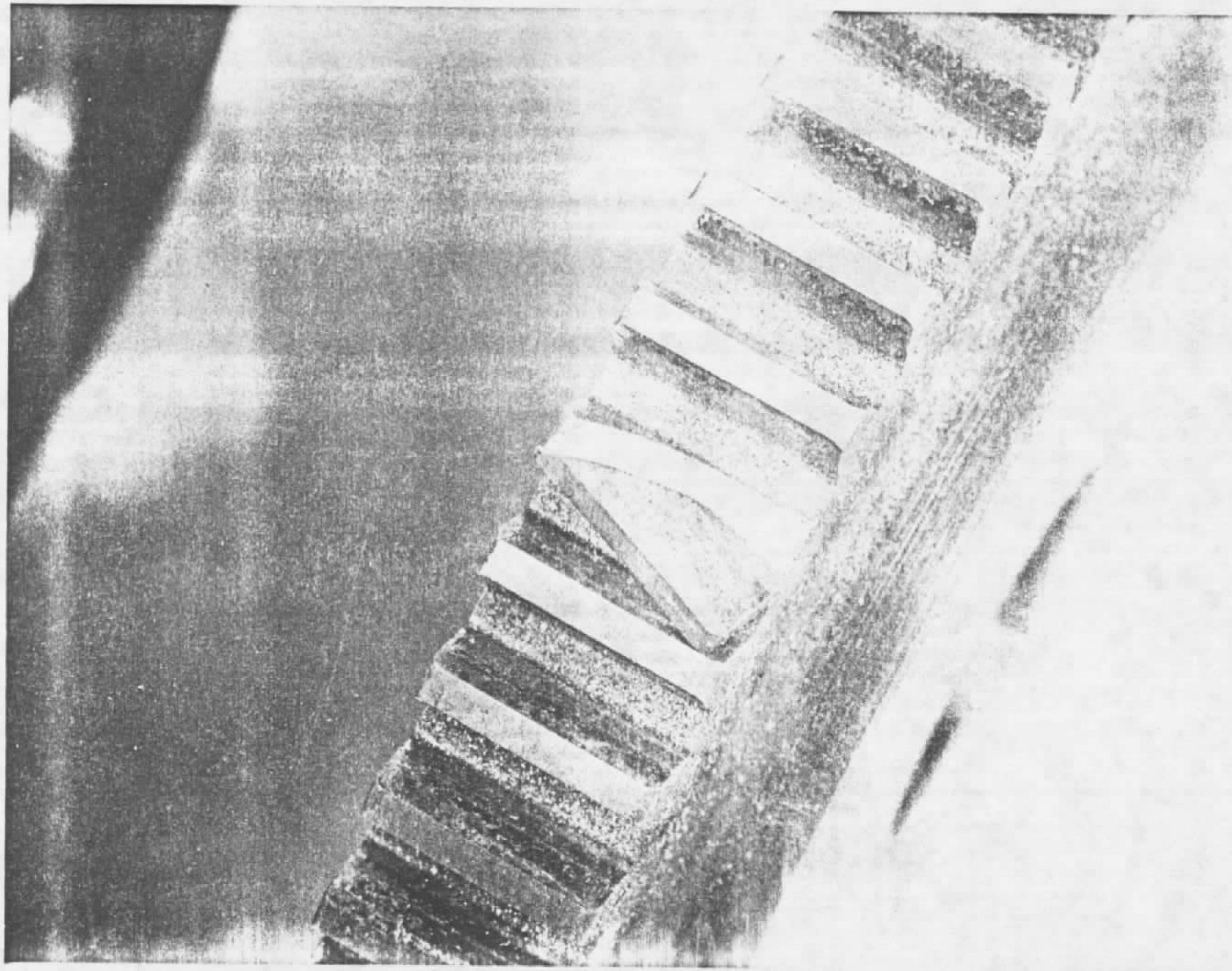


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Fig. 15 12-D.P. Nodular Iron Gear (Position 3) which Failed in Shear after 17 hr in Test 2

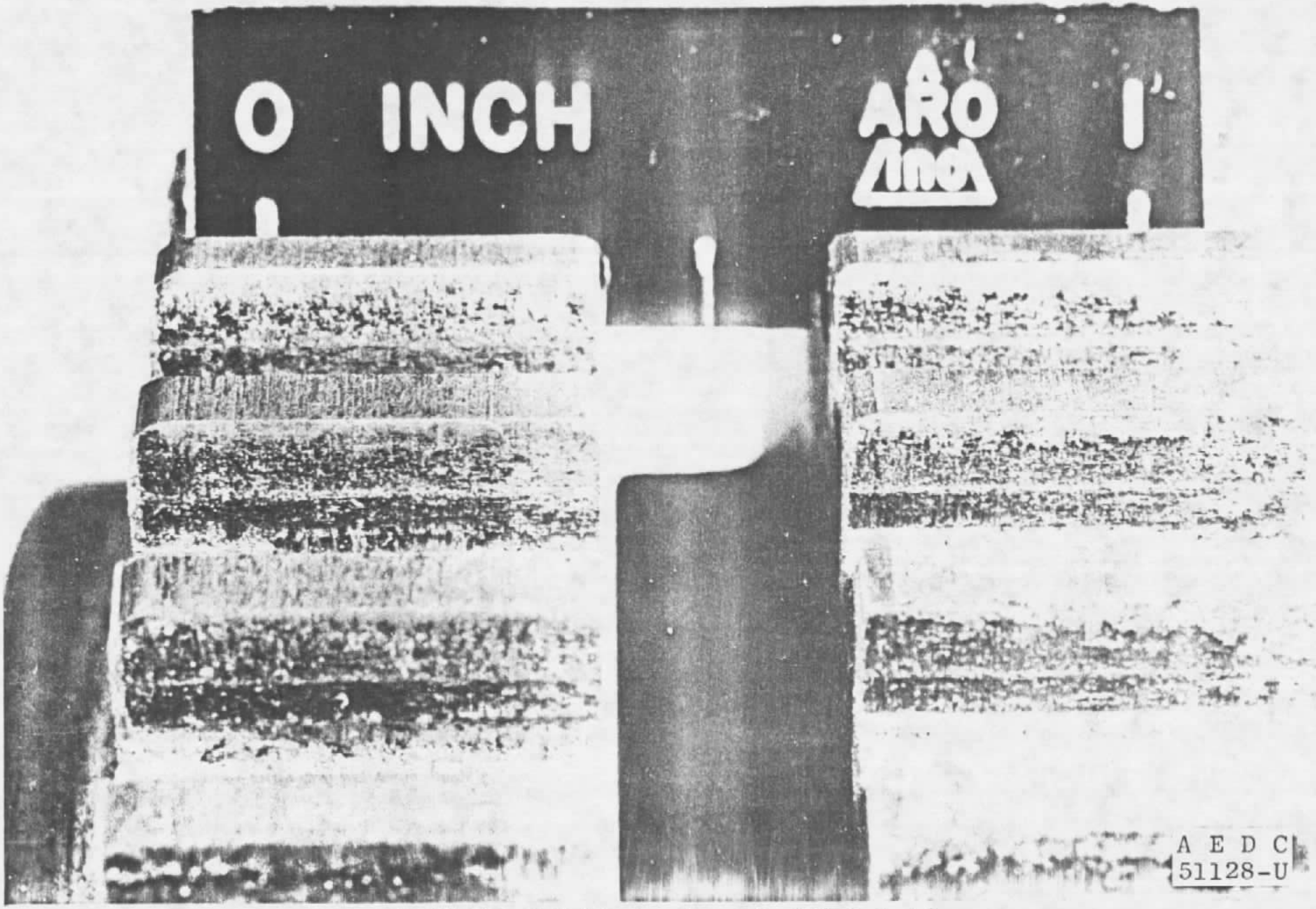
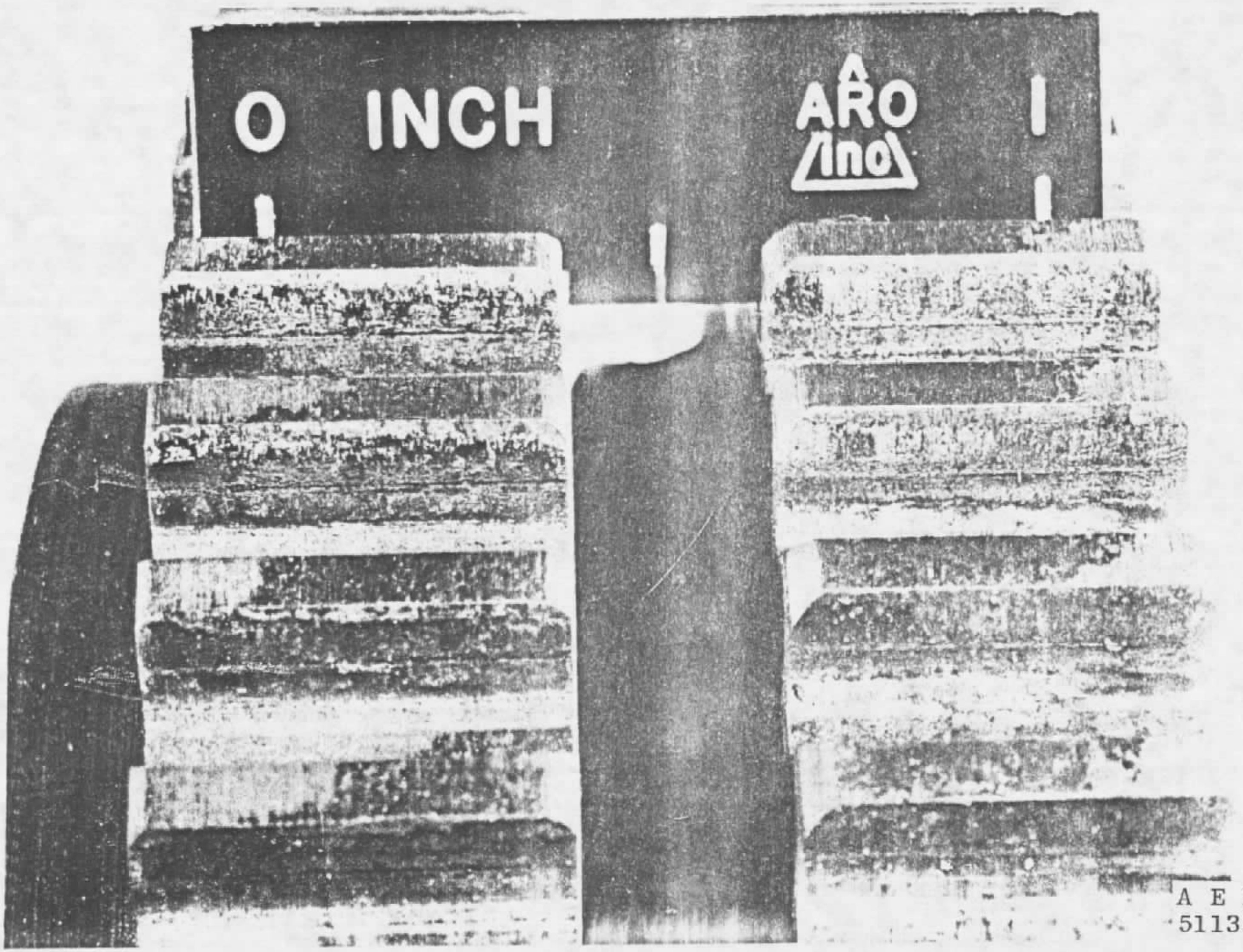


Fig. 16 12-D.P. Nodular Iron Gears after 17 hr in Test 2



A E D C
51133-U

Fig. 17 12-D.P. Nodular Iron Gears after 83 hr in Test 2

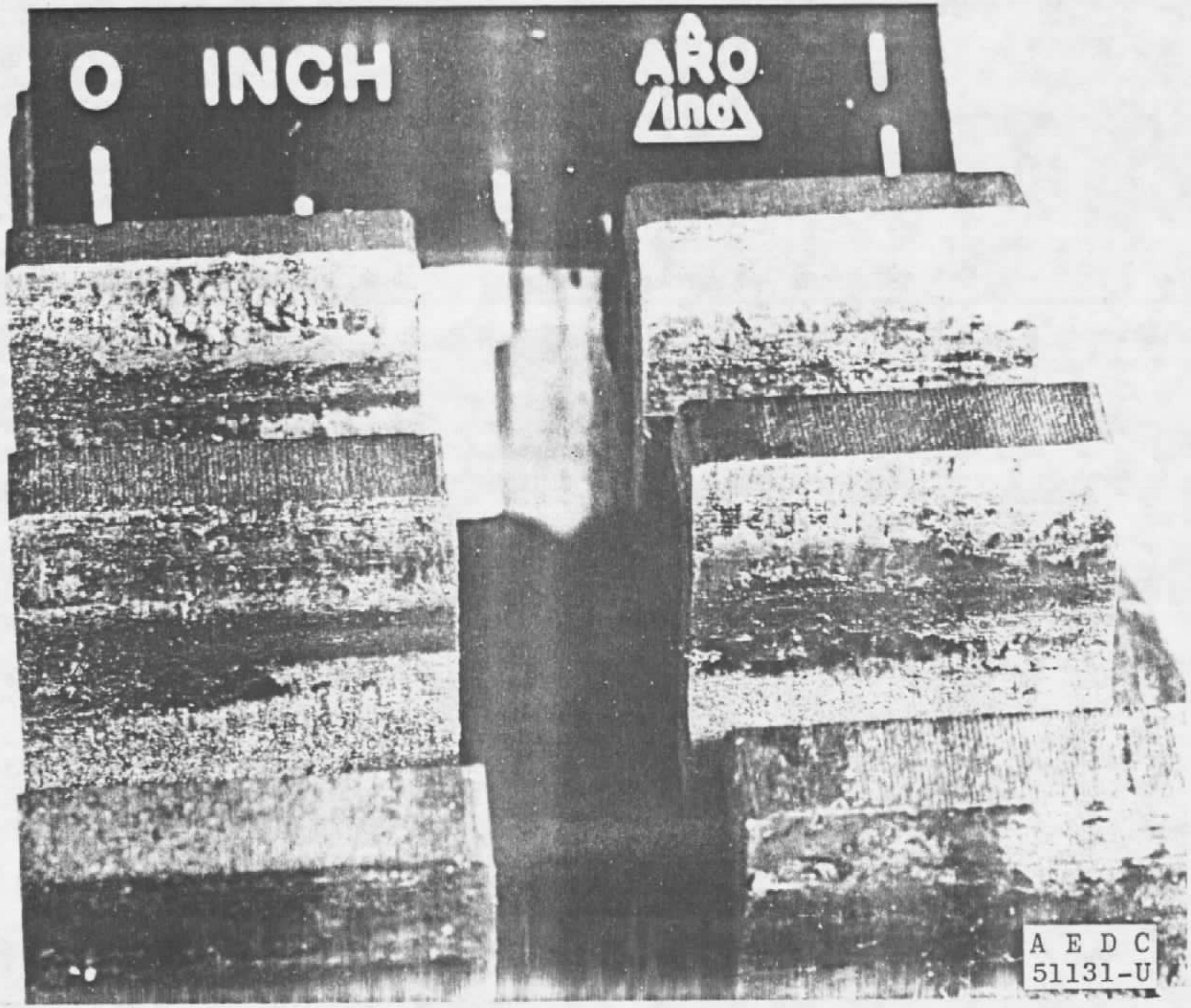


Fig. 18 7-D.P. Nodular Iron Gears after 100 hr in Test 2

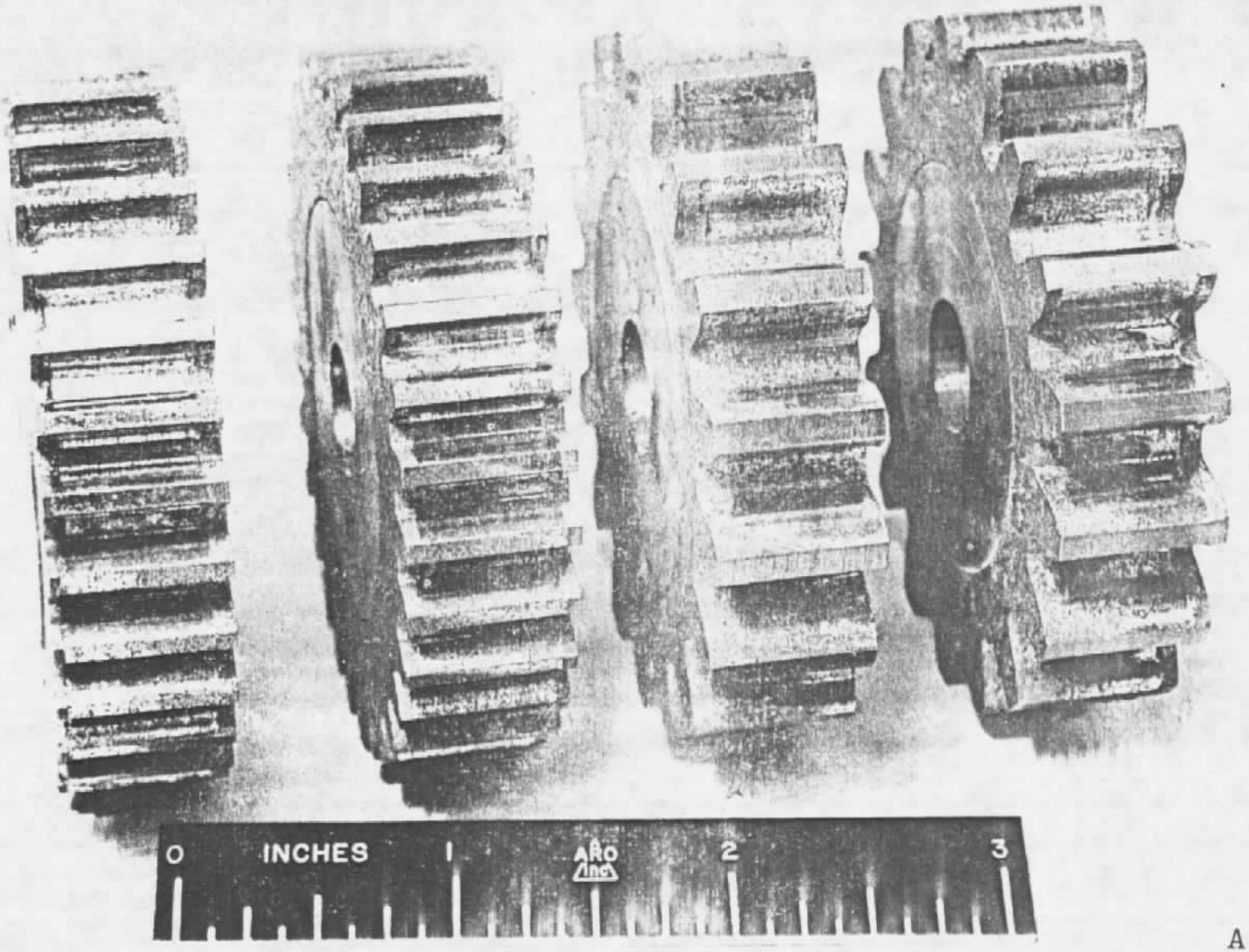


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Fig. 19 Lubricating Idlers Used in Test 2

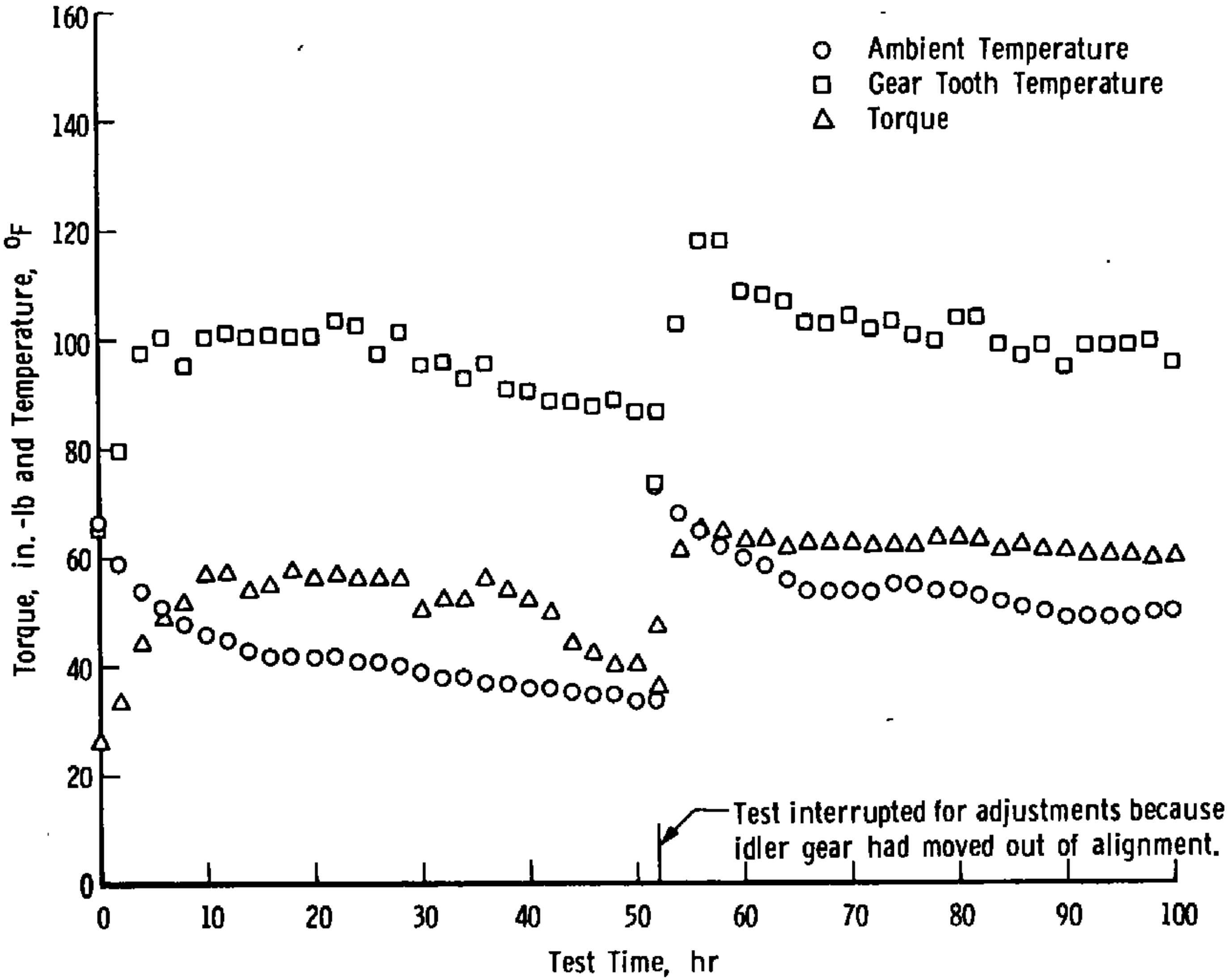

Fig. 20 Drive Torque, Gear Tooth Temperature, and Chamber Ambient Temperature versus Test Time for Test 3

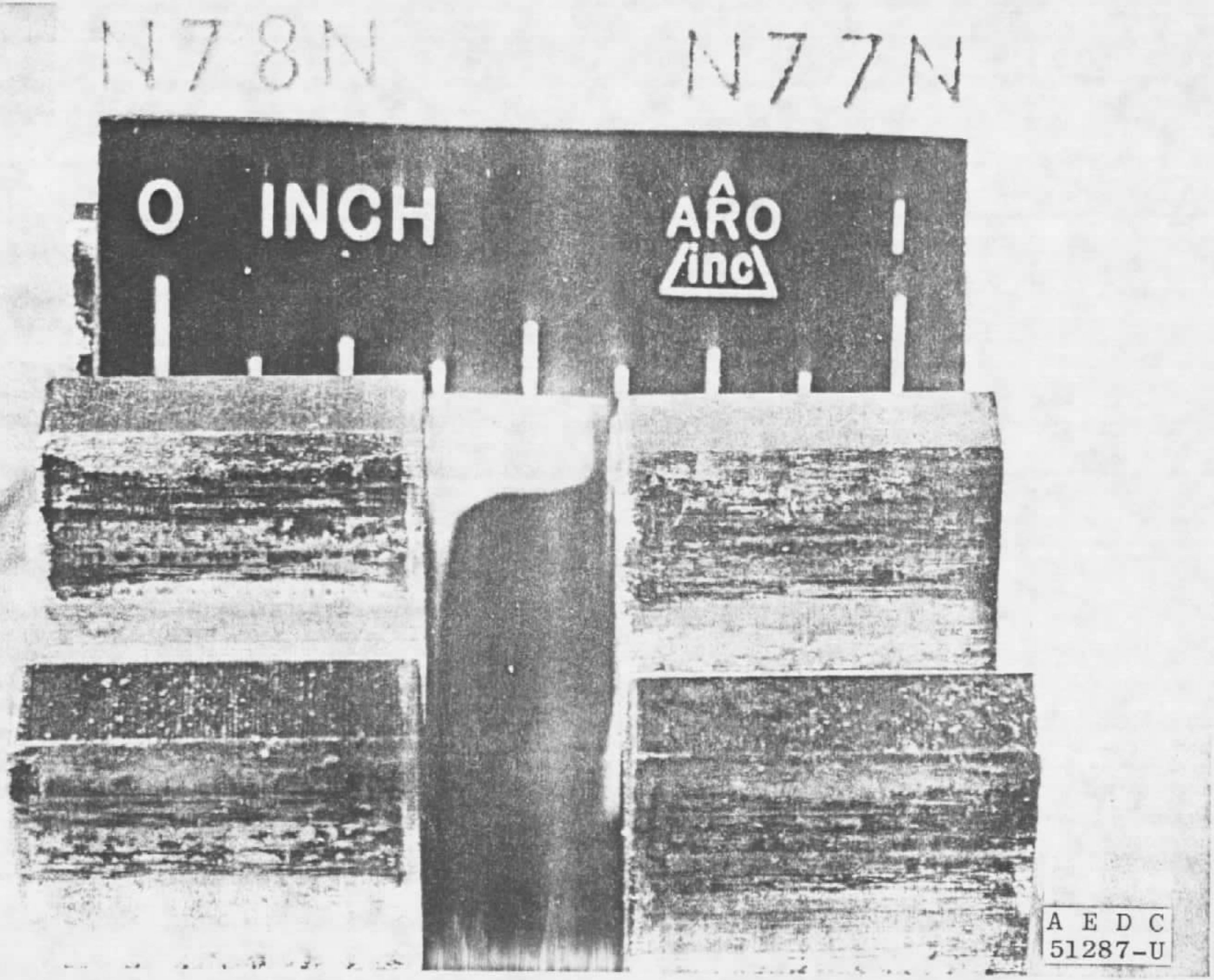

Fig. 21 7-D.P. Steel Gears after 100 hr in Test 3

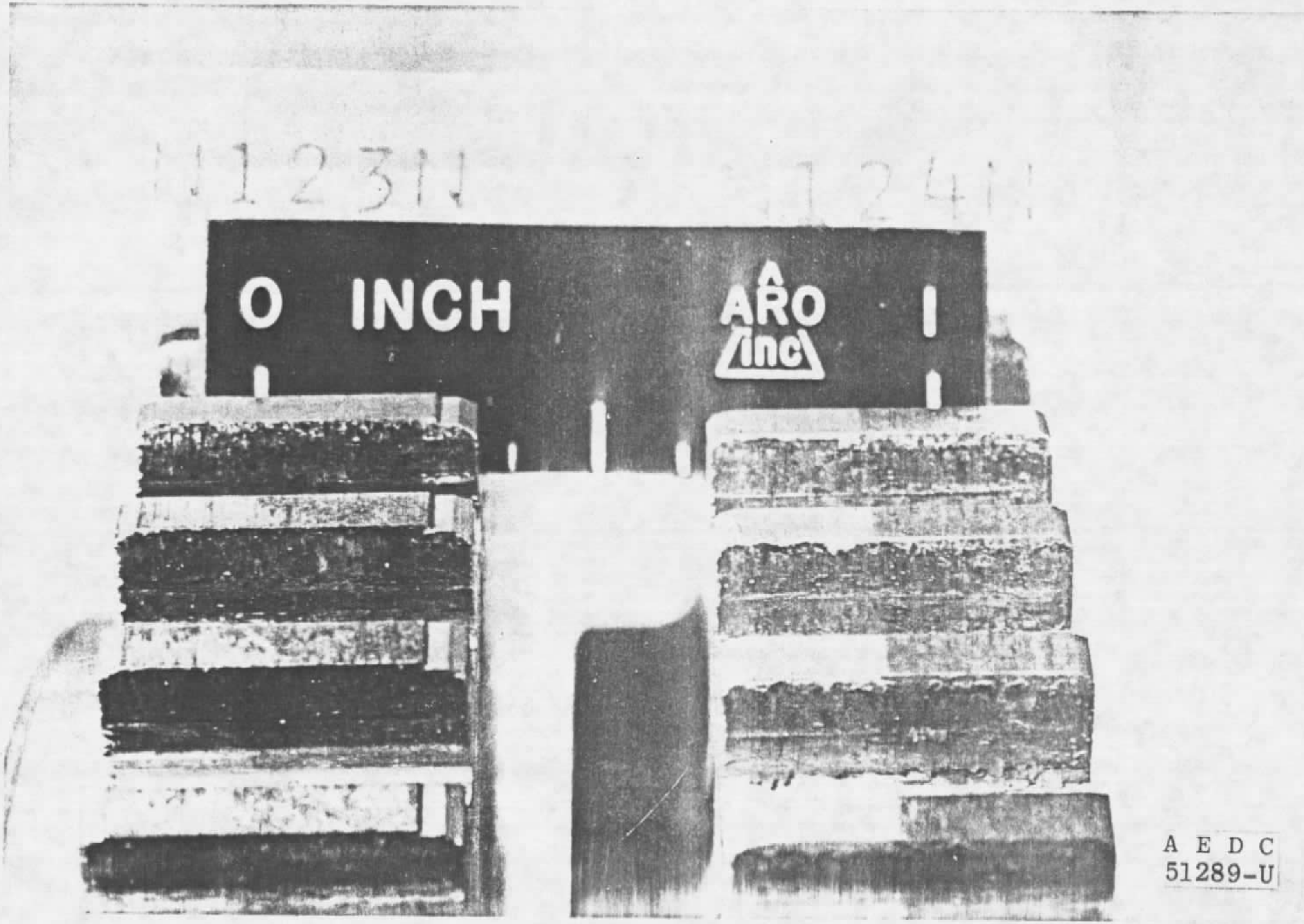

Fig. 22 12-D.P. Steel Gears after 100 hr in Test 3

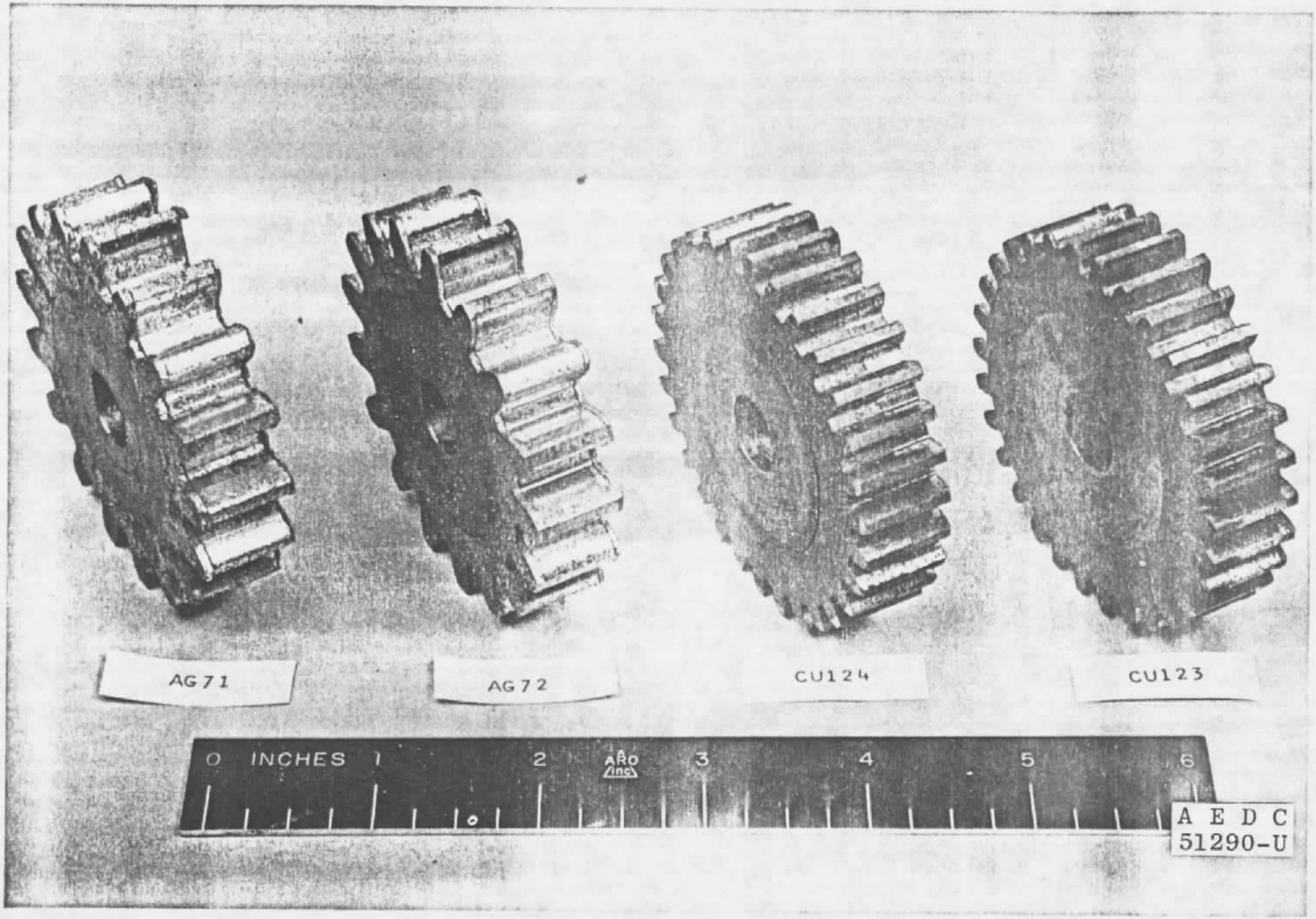

Fig. 23 Lubricating Idlers Used in Test 3

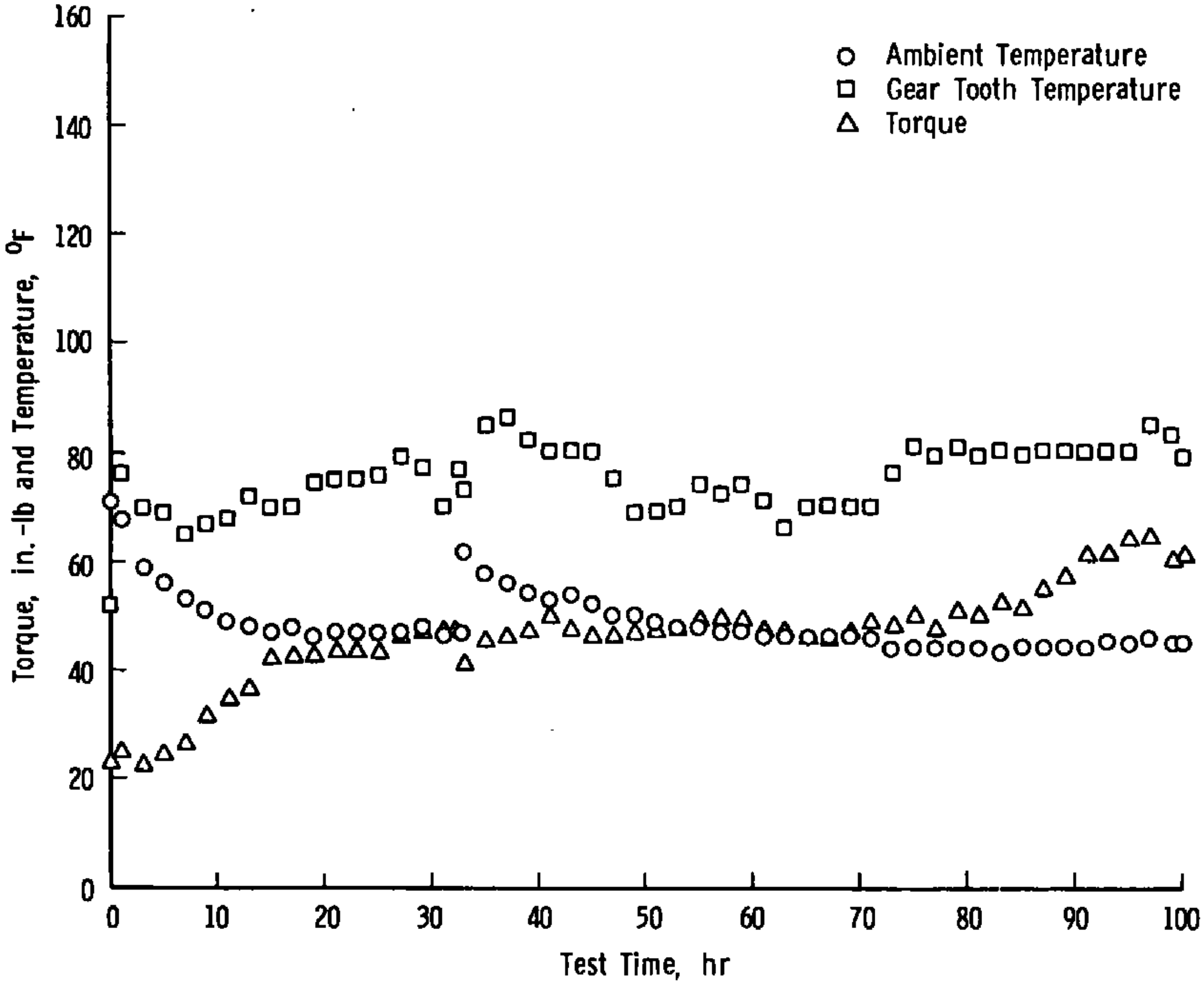

Fig. 24 Drive Torque, Gear Tooth Temperature, and Chamber Ambient Temperature versus Test Time for Test 4

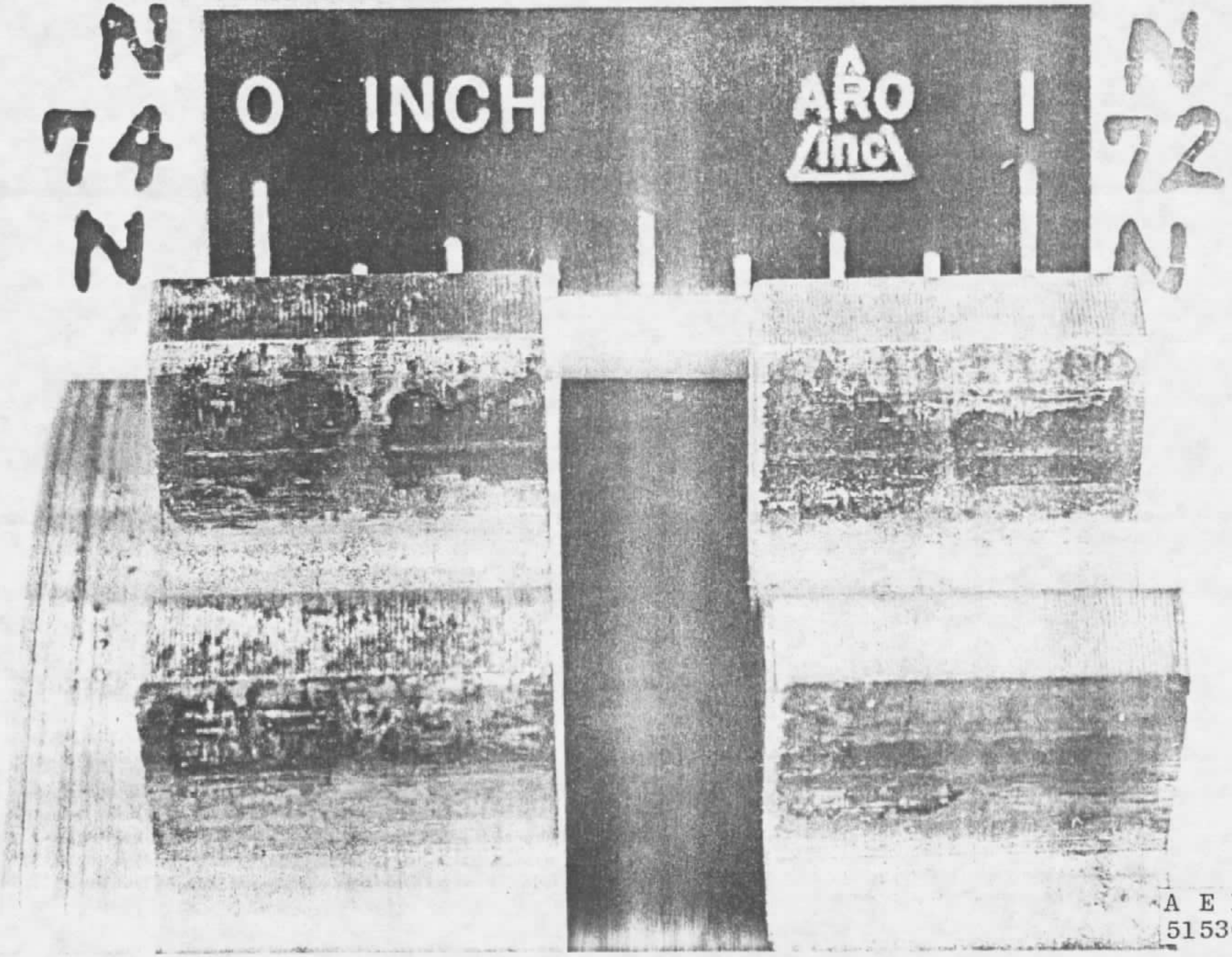

Fig. 25 7-D.P. Steel Gears after 100 hr in Test 4

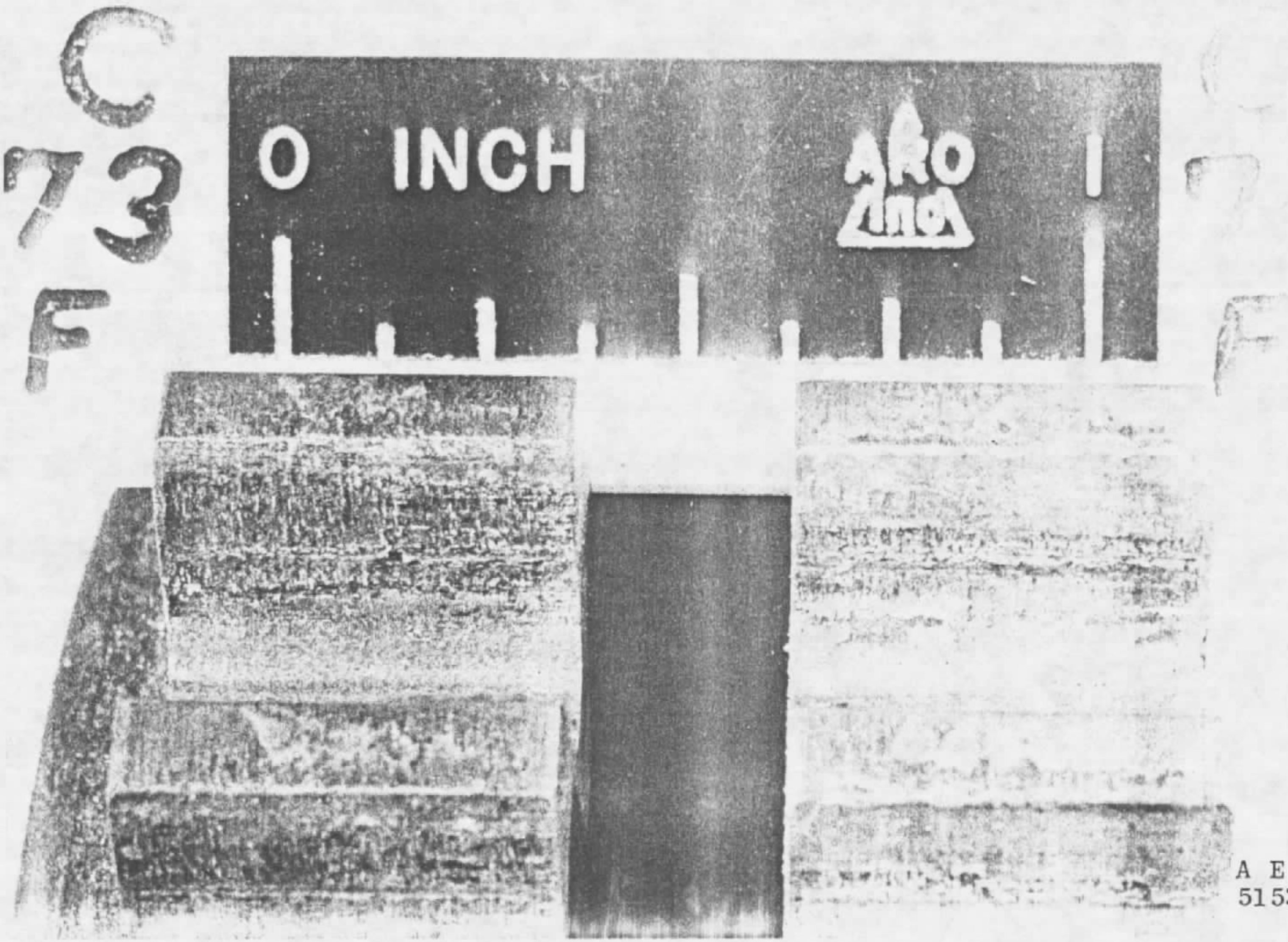

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Fig. 26 7-D.P. Nodular Iron Gears after 100 hr in Test 4

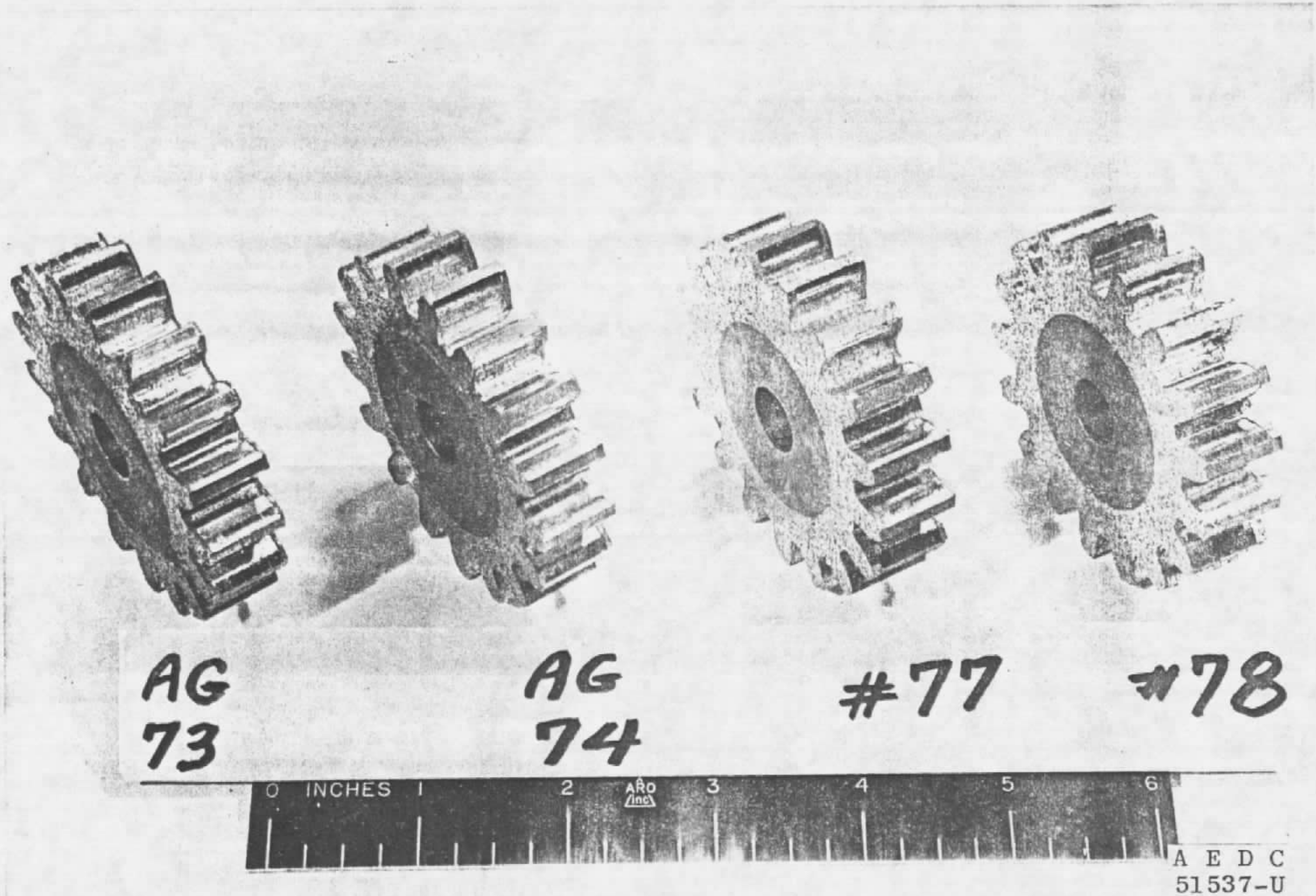
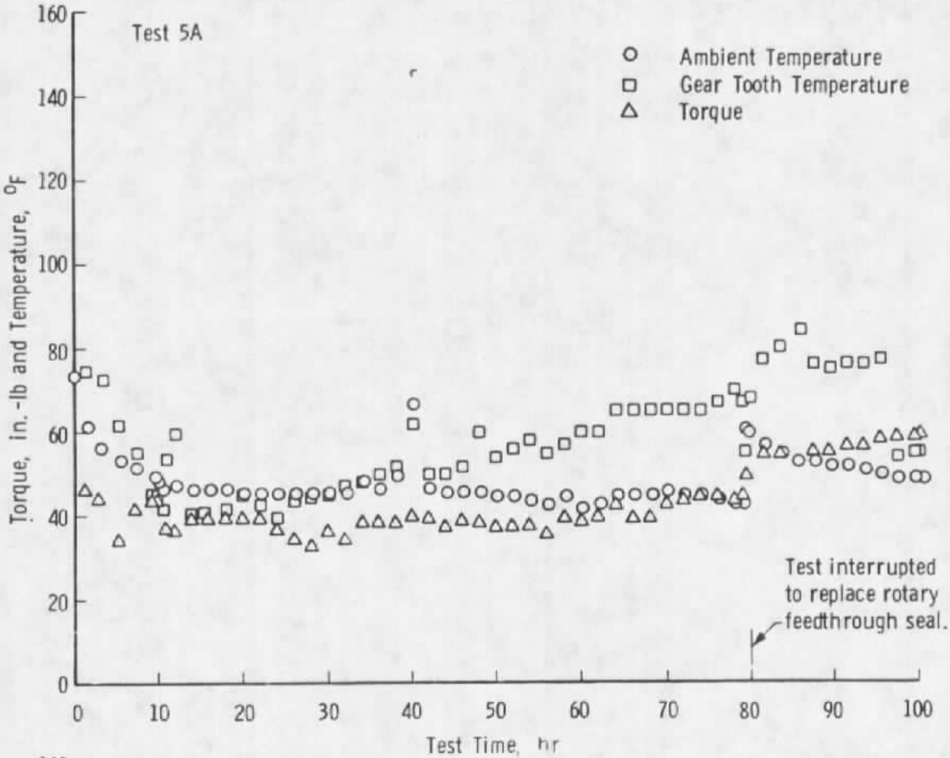


Fig. 27 Lubricating Idlers Used in Test 4



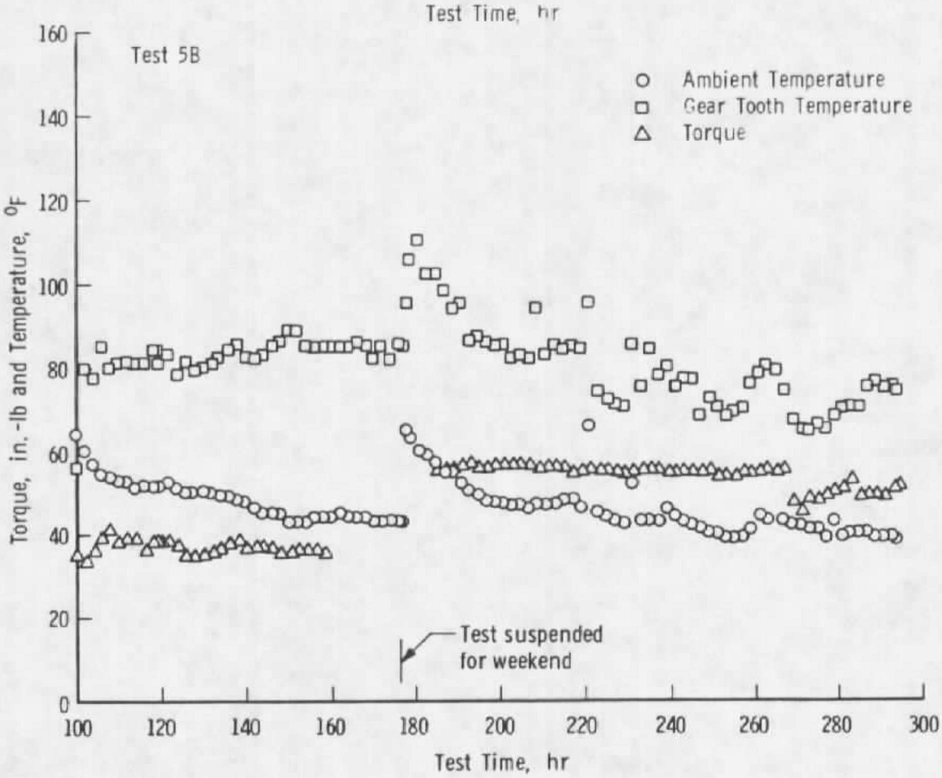


Fig. 28 Drive Torque, Gear Tooth Temperature, and Chamber Ambient Temperature versus Test Time for Tests 5A and B

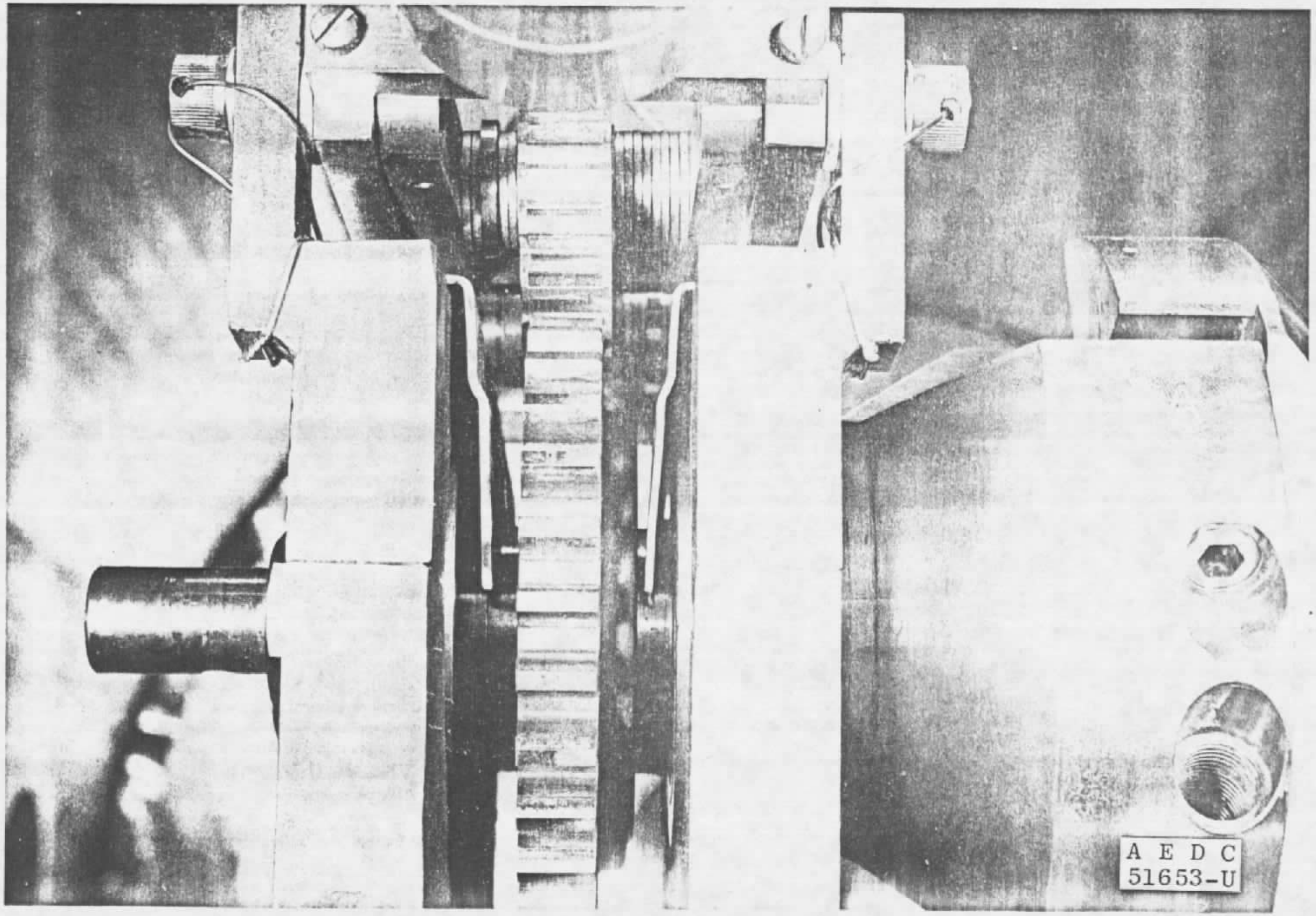


Fig. 29 7-D.P. Nodular Iron Gear and Cu + PTFE + WSe_2 Idler after 100 hr in Test 5A

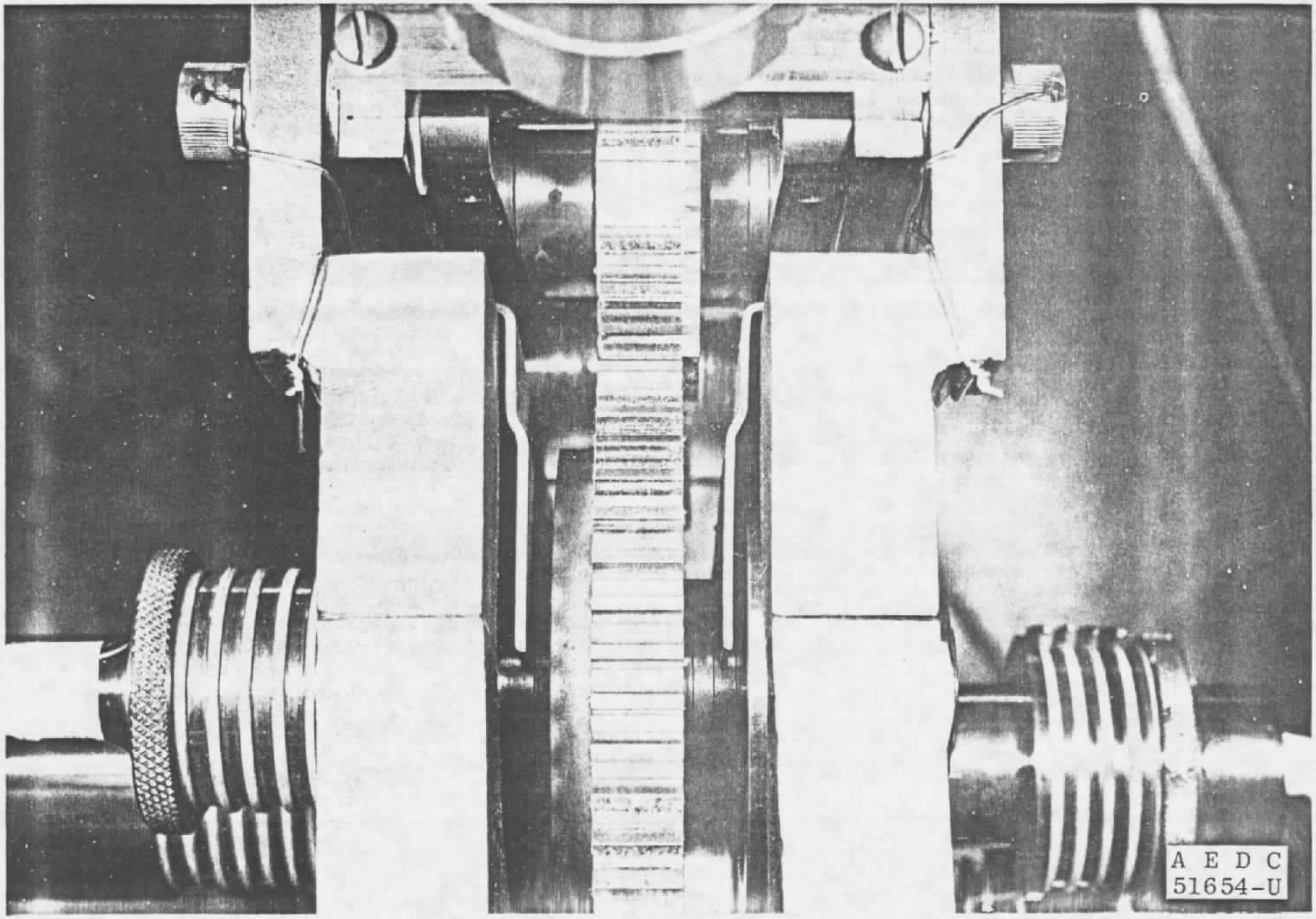


Fig. 30 12-D.P. Nodular Iron Gear and Special Alloy + WSe_2 Idler after 100 hr in Test 5A

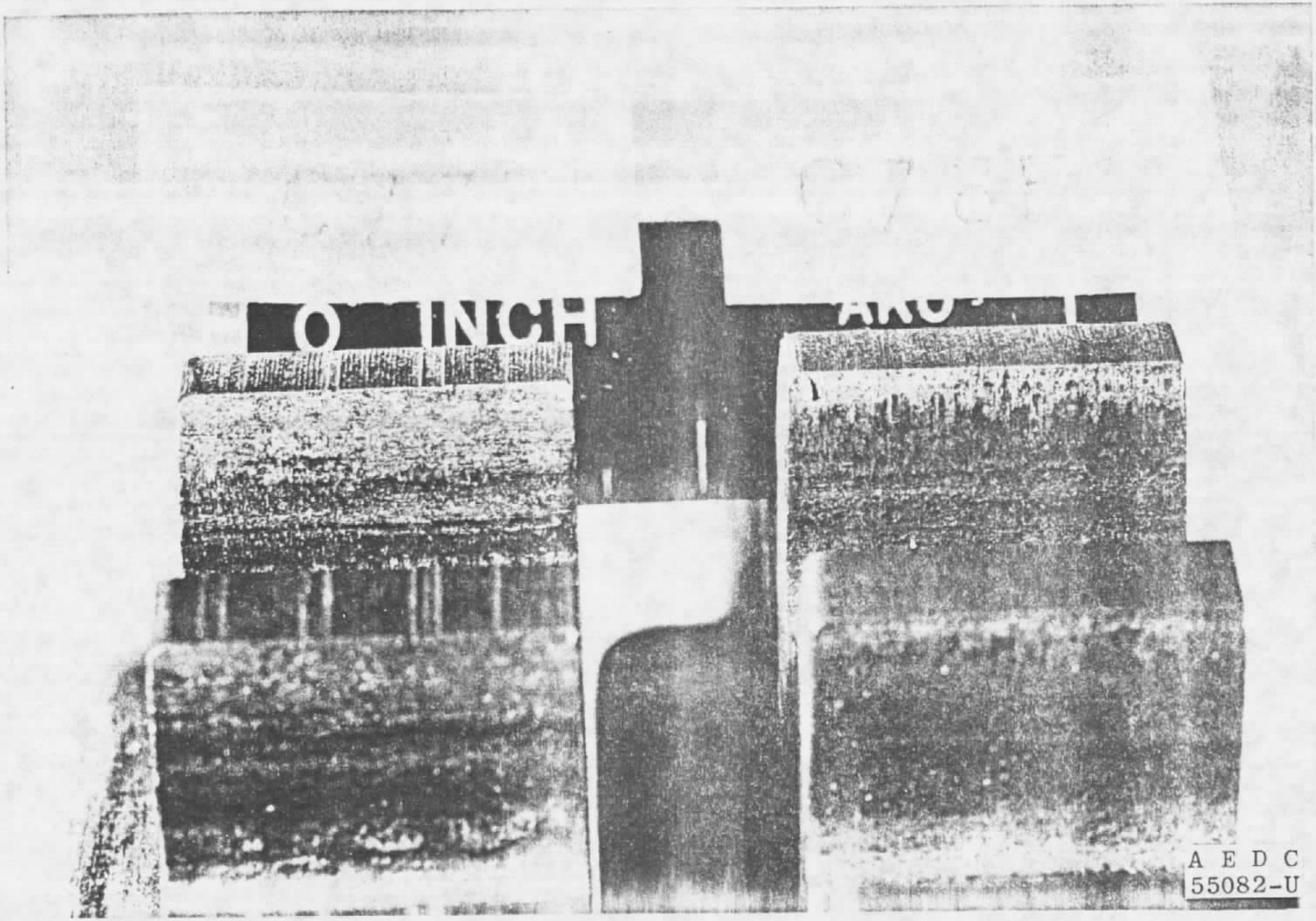


Fig. 31 7-D.P. Nodular Iron Gears after 200 hr in Test 5B

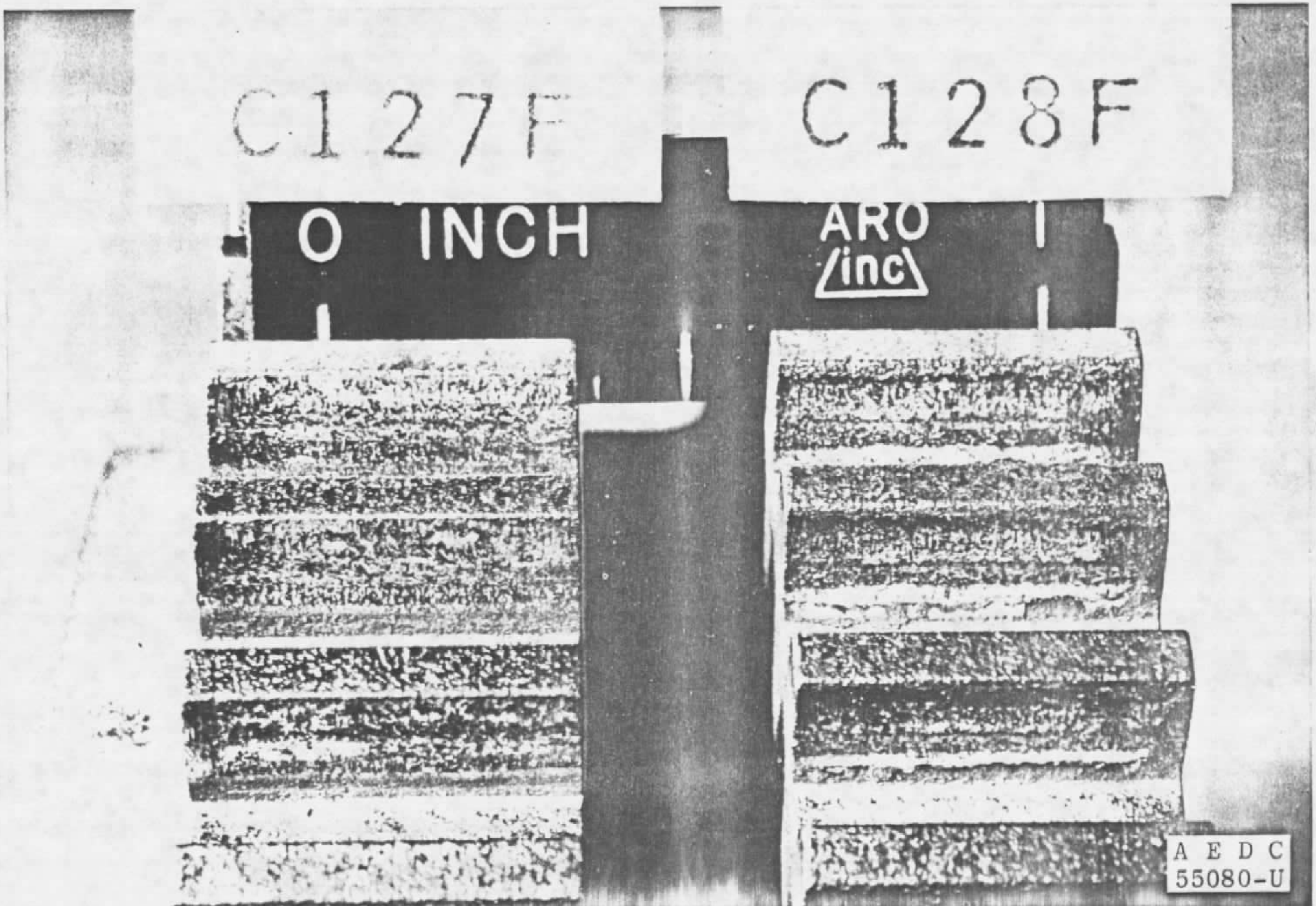


Fig. 32 12-D.P. Nodular Iron Gears after 200 hr in Test 5B

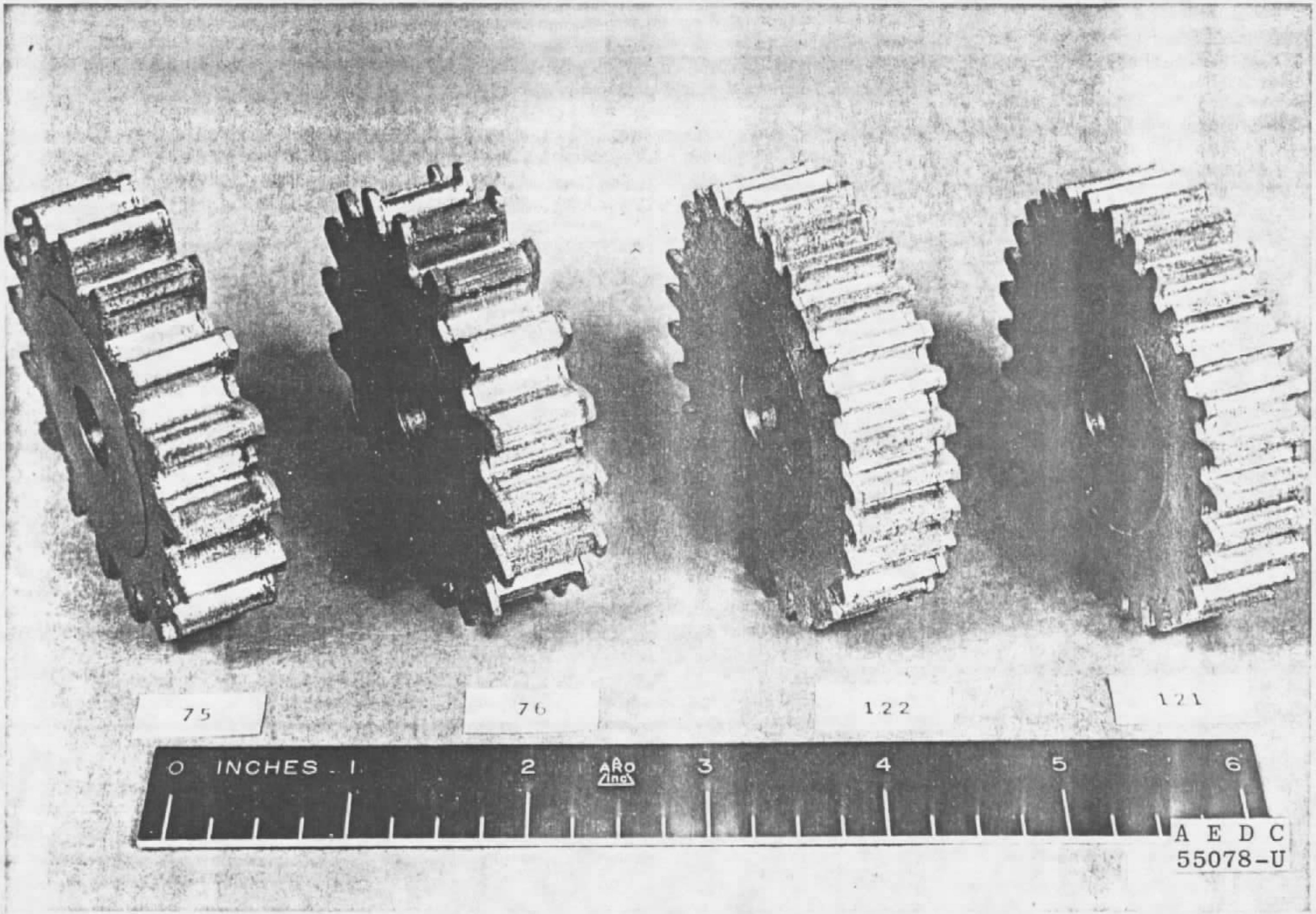


Fig. 33 Lubricating Idlers Used in Tests 5A and B

TABLE I
GEAR TEST CONDITIONS AND RESULTS

Test	Test Gears	Diametral Pitch	Lubricants	Preload Torque, in.-lb	Tangential Tooth Load, lb	Test Duration, hr
1	2 steel	7	Cu + PTFE + WSe_2	600/1100	290/532	100
	2 nodular iron	7	Apiezon "L" Grease	600	290	40
	2 nodular iron	12	Ag alloy + PTFE + WSe_2	1100	532	60
2	2 nodular iron	7	Cu + PTFE + WSe_2	1100	532	100
	2 nodular iron	12	Cu + PTFE + WSe_2	1100	532	17*
	2 nodular iron	12	Cu + PTFE + WSe_2	1100	532	83
3	2 steel	7	Ag alloy + PTFE + WSe_2	1100	532	100
	2 steel	12	Cu + PTFE + WSe_2	1100	532	100
4	2 steel	7	Ag alloy + PTFE + WSe_2	1100	532	100
	2 nodular iron	7	Ag alloy + PTFE + WSe_2	1100	532	100
5A & B	2 nodular iron	7	Cu + PTFE + WSe_2	1100	532	300
	2 nodular iron	12	alloy** + WSe_2	1100	532	300

*Test terminated at end of 17 hours because of broken gear tooth.
**Proprietary Alloy

TABLE II
LUBRICATING IDLER GEAR WEIGHT LOSS

Test No.	Position	Idler	Original Weight, gm	Wt Loss, gm	Wt Loss, percent	Test Duration, hr
1	I-1	Cu 71	318.891	4.081	1.279	100
1	I-3	Ag 121	383.724	0.528	0.137	60
2	I-1	Cu 73	321.102	0.994	0.309	100
2	I-2	Cu 74	315.650	1.460	0.462	100
2	I-3	Cu 121	336.308	1.604	0.477	100
2	I-4	Cu 122	337.332	1.264	0.374	100
3	I-1	Ag 71	354.380	14.23	4.015	100
3	I-2	Ag 72	349.000	8.03	2.300	100
3	I-3	Cu 123	337.790	1.77	0.523	100
3	I-4	Cu 124	336.220	0.73	0.217	52
4	I-1	Ag 77	369.651	1.14	0.308	100
4	I-2	Ag 78	370.857	3.057	0.824	100
4	I-3	Ag 73	345.212	3.890	1.126	100
4	I-4	Ag 74	352.038	3.420	0.971	100
5A	I-1	Cu 75	308.293	1.895	0.614	100
5A	I-2	Cu 76	315.065	4.290	1.361	100
5A	I-3	A 121*	402.395	4.385	1.089	100
5A	I-4	A 122*	404.394	3.224	0.797	100
5B	I-1	Cu 75	306.398	6.785	2.214	200
5B	I-2	Cu 76	310.775	15.295	4.921	200
5B	I-3	A 121*	398.010	7.460	1.874	200
5B	I-4	A 122*	401.170	5.460	1.361	200

*Proprietary Alloy

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13 ABSTRACT

This report contains the results of a test program set up to determine the operational characteristics of dry composite lubricated gears. Two diametral pitch sizes, 7 and 12, and two gear materials, nitralloy steel and nodular iron, were tested. Three dry composite lubricants and one low vapor pressure grease were tested. All three dry composite lubricants provided adequate lubrication for periods of up to 300 hr at 100 rpm with very little wear of either load gears or lubricating idlers. The MoS_2-fortified, grease-lubricated gears failed after 40 hr of operation.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Lubrication						
Dry Composite Lubricants						
Environmental Facilities						

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